INDIAN
FOREST UTILIZATION

VOLUME I

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Compiled and written at the Editorial Board,
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PART I

EXTRACTION, CONVERSION AND MARKETING OF TIMBER

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PREFACE

Forest Utilization is defined as the process of harvesting, converting and disposing of forest produce and other resources of the forest. Forest produce can be broadly classified into "Major Forest Produce" (viz., timber and fuel), and "Minor Forest Produce" (covering all forest products other than wood). Thus the subject of Forest Utilization deals not only with the extraction, processing and marketing of timbers, their structural characteristics, defects, seasoning and preservation behaviour, etc. which have a direct bearing on the various uses of wood, but also with the collection, processing and utilization of a wide range of minor forest products, e.g., fibres and flosses, grasses, bamboos and canes, essential oils, oilseeds, tans and dyes, gums and resins, drugs and spices, etc. It also encompasses the forest-based industries, such as those manufacturing matchwood, composite wood, paper and rayon, lac and shellac, rosin and turpentine, katha and tannin, etc.

The need for a general text-book on Indian Forest Utilization, embodying up-to-date basic knowledge and data pertaining to various utilization aspects of forest products, which would serve the needs of the students of the Forest Colleges and also serve as a reference manual for practical foresters and those connected with this subject in one way or the other, is obvious. One of the earliest books, Troup's "Indian Forest Utilization", was published in 1907 and revised in 1912. This was followed by Trotter's "Manual of Indian Forest Utilization" in 1940. Since then no other general text-book has been published on the subject, though considerable data have been collected as a result of research on the forest products carried out during the last quarter of a century at the Forest Research Institute. Trotter's Manual is now out of print, and also obsolete and inadequate in several respects. It was, therefore, decided to bring out a comprehensive book on this subject. The job of collecting and compiling the requisite material and, wherever necessary, writing up the chapters with the co-operation of the concerned Branch Officers, was assigned to the Editorial Board of the Forest Research Institute, in 1965. While a few of the chapters were contributed by the Branch Officers concerned, the others were all written up at the Editorial Board itself with the information furnished by the Branch Officers or obtained from various publications. It is hoped that this book, which is not a mere revision of Trotter's work but a comprehensive new version with a much broader scope, will fulfil the long-felt need for a book on the subject.

Acknowledgements : The Editorial Board collected information from Troup's and Trotter's Manuals on the subject, numerous other publications, mostly of the Forest Research Institute, such as the *Indian Forester, Indian Forest Records, Indian Forest Bulletins, Indian Forest Leaflets*, and additional material supplied by the various Branch Officers.

Most of the forty-one chapters were written by Shri P. Venkataramany, I.F.S., Editor, and some by Shri S. V. Venkataramanan, Assistant Editor. Vetting, editing and finalization of these chapters, incorporating suggestions of Branch Officers, were done by Shri S. V. Venkataramanan and his successor Shri Ram Parkash, I.F.S.; the latter also processed the material for the press, providing suitable illu[strations], appendices, index, etc., and corrected the proofs. The contribution of these officers of t[he] Editorial Board is appreciated. Research Assistants Sarvashri M.P. Shiva, P. C. Gupta, D. C. Chaudh[ary] and R. S. Chauhan gave them necessary assistance.

The compilation of a publication of this kind would not have been possible but for the active c[o]operation of a number of officers of the Forest Research Institute and Colleges who rendered valuab[le] assistance in one form or the other. Special mention may be made of Shri A. C. Sekhar for contributi[ng] Chapters V, IX, X; Shri K. Ramesh Rao for Chapters VIII, XXIII, XLI; Shri M. N. Asthana, I.F.S., for Chapters I and II; Shri M. G. Karnik for Chapter XIX; Shri S. N. Sharma for Chapters XII a[n]d XIV; Dr. S.R.D. Guha for Chapter XVIII; Dr. P.S. Rao for Chapter XI; Dr. B. K. Bakshi and Dr. P. N. Chatterjee for parts of Chapter XIII; Shri J. N. Pande for Chapter XVI (in collaboration w[ith] Shri P. Venkataramany), and Shri B.N. Prasad for Chapter XL (jointly with Shri S. V. Venk[atara]manan).

Acknowledgements are also due to Shri N. J. Masani, Dr. P. S. Rao, Shri A. C. Sekhar, Shri N. C. Jain, Shri M. G. Karnik, Shri S. N. Sharma and Dr. R. R. Fernandez, and to some of the retired senior officers of this Institute, viz., Dr. D. Narayanamurti, Shri M. A. Rehman and Shri M. M. Srinivasan, I.F.S., for supplying material for writing up the chapters relating to their respective fields and, in some cases, for vetting the final drafts.

Among the officers who scrutinized and made valuable suggestions in respect of some of the chapters pertaining to their Directorates or Branches, mention may be made of Shri I. M. Qureshi, I.F.S., Dr. A. Purushotham, Shri H. C. Day, I.F.S., Shri T. Krishnamurthy, I.F.S., Dr. H. S. Rao and Shri V. P. Jaitly.

Shri Subhash Chander, Draftsman, Publicity and Liaison Branch, prepared most of the sketches for making blocks for illustrations. Sarvashri P. D. Joshi, M. P. Agarwal, D. P. Verma, K. L. Thakur and G. D. Baluni did a good job in handling the voluminous typing work from time to time during their tenure at the Editorial Board.

T. N. SRIVASTAVA,
President
Forest Research Institute & Colleges.

Dehra Dun
25th January, 1969.

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˛am type axe
Axe used in Bahraich, U.P.

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CHAPTER I

LOGGING—1. FELLING AND CONVERSION

Implements Used in Felling and Conversion

Axes, saws and wedges are the conventional implements used in felling and conversion.

Axes :

In India, felling axes cover a wide range both in size and shape. Most types possess some advantage or other, and each type is no doubt considered to be the best by the man accustomed to use it.

The chief purposes for which axes are used are : (1) felling, (2) trimming, (3) splitting, and (4) ubbing; and for each of these purposes a different type of axe is used, though most felling axes can, necessary, be used for all purposes. Nevertheless, it is not so much the axe as the skill of the man ho uses it that makes for good work.

Description of felling axes.—Axes consist of two parts, (i) the iron head and (ii) the wooden handle. The axe head carries a socket called the eye, into which the handle fits. The portion of the iron head front of the eye is known as the blade, and that on either side of and behind the eye is known as the ack of the axe.

(i) *The axe head.*—The best type of axe head is either a solid piece of iron with a steel edge welded on to it, or two tapering pieces of iron between which a narrow wedge of steel is introduced. This projects slightly beyond the two pieces of iron to form the edge. Steel permits a sharper edge being ground and is far more durable than iron.

The edge of the blade should be sharp and of the proper temper, neither too soft, in which case it would bend, nor too brittle causing it to chip. The temper of the edge should suit the hardness of the wood to be cut. Proper temper is particularly important for hardwood trees as compared to softwood trees. As regards the shape, the blade should be in the form of a tapering wedge; preferably the sides should be slightly convex in front of the eye as this reduces friction and renders the head less likely to stick in the cut. In addition, this has the effect of accumulating the weight just in front of the eye, and this gives the best balance for delivering an effective stroke. The edge of the blade should be slightly curved; this produces better penetration and renders the corners less liable to break off.

The weight of the axe head is conditioned, apart from the strength of the wood-cutter who uses it, by the hardness of the wood to be cut and the size of tree to be felled. The softer the wood, the more easily are its fibres crushed and displaced, whereas in hardwoods the axe can do very little crushing or splitting and cuts chiefly by severing the fibres. Hence for hardwoods the blade of an axe should be comparatively lighter and thinner than for softwoods. Moreover, if an axe is driven too far into a hardwood, it is difficult to pull it out again and this is likely to happen when a heavy axe is used. The weight of an ordinary felling axe head varies from 0.7 kg to 1.8 kg ($1\frac{1}{2}$ to 4 lb), but in some localities even the latter weight is slightly exceeded, while for cutting small poles and saplings in coppice fellings a very light lopping axe, even under 0.7 kg ($1\frac{1}{2}$ lb), may be employed. However, in no case should an axe be heavier than is absolutely necessary, as the heavier the axe the sooner the woodman gets fatigued and the less will be the amount of work done.

Among Indian axes, the Malabar axe, which is extensively used on the West Coast for felling large trees and for rough-squaring of logs, needs special mention. It consists of a wedge-shaped head fitting in to a hole in the handle. The hole is rectangular in shape tapering towards the back, and is strengthened by two iron rings shrunk on the handle, one above and the other below the hole. The handle is slightly curved, round at the upper (axe head) end and oval at the lower end. A particularly heavy broad-bladed axe is used for squaring of logs in the Himalayas, where the workman stands on the log and lets the weight of the falling axe do most of the work.

(i) *The axe handle.*—In India round handles fitting in round eyes are almost always used. Round handles are easily made and fitted; and should a handle break, it can be replaced on the spot by cutting

a solid bamboo or a straight piece of tough wood. A disadvantage in this type is that round ha are liable to slip round in the eye. European and American axes usually have oval-shaped handles eyes. In their case, the handle cannot slip round in the eye, and allows a thinner and more tap blade to be used. That part of the handle which fits into the eye is split, and a tight fit is obtai driving in a hard wooden wedge between the two sides. This method should always be adopted in tool handles with metal heads. It not only holds good with axes, but also with other tools like axes, hammers and Indian hoes. Wetting the wood round the axe head also helps to obtain a tight the wood swells and automatically tightens the fit. Malabar handles, like the European and Ame handles, are not straight but are curved in a way that aids the grip of the handle and improves the balan of the whole axe when it is being swung. The chief disadvantage of these handles is that they canno be replaced easily unless spares are kept in stock. They are, in addition, rather liable to break just below the eye when used by labour unaccustomed to them, but in the hands of experts the cut and powe of axes fitted with such handles is tremendous.

Fig. I—1 illustrates some of the types of axes.

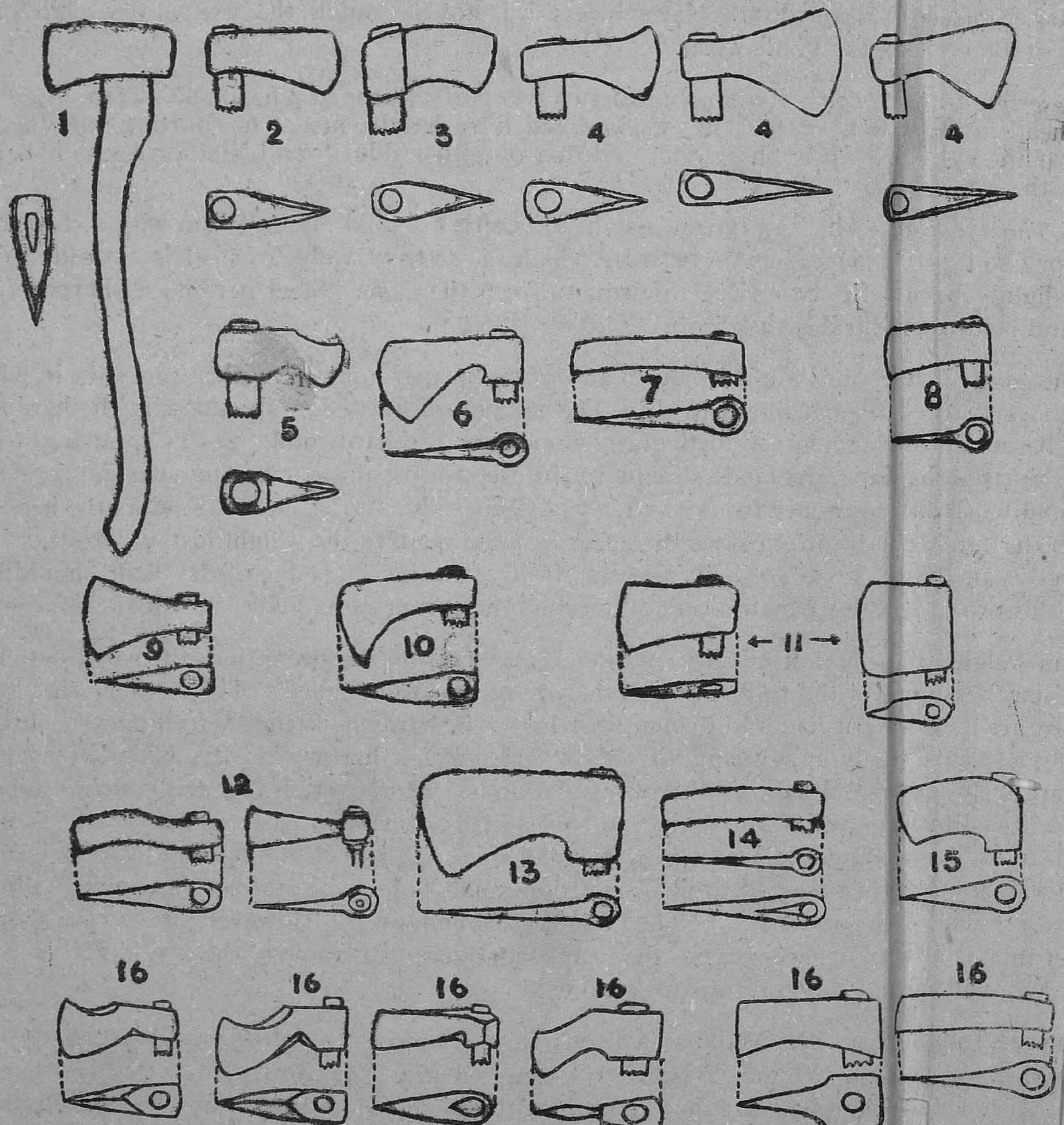

Fig. —I—1. Axes used for felling and trimming (one-tenth natural size).

1. American axe
2. Nimar pattern axe
3. Amritsar patten axe
4. Axes used in North-Western Himalayas
5. Gond pattern axe
6. *Pahari* axe
7. Madras type axe
8. Bombay type axe
9. Hyderabad (D.) axe
10. Kashmir axe
11. Assam type axe
12. Sundarban ax
13. Delhi axe
14. Axe used in Bahraich, U.P.
15. Punjab axe
16. Madhya Pradesh type axes

The action of the axe.—The action of an axe is to sever, to crush and to shear. The severing and shearing actions are in direct, and the crushing action in inverse, proportion both to the sharpness of the edge and to the thinness of the blade. When an axe is driven at right angles to the fibres, there is no shearing action at all, only severing and crushing, but when the blow is delivered obliquely, all three actions take place and the axe produces its greatest effect. Another reason why the obliquely driven axe penetrates further is that the lower lip of the wound it makes (Fig. I—2) bends easily downwards and thus widens the gap, so as to allow the blade to continue its onward motion; whereas when the cut is perpendicular to the axis of the tree the severed fibres have to be crushed away longitudinally to produce a wider opening for the entry of the thicker hind portion of the blade into the wound.

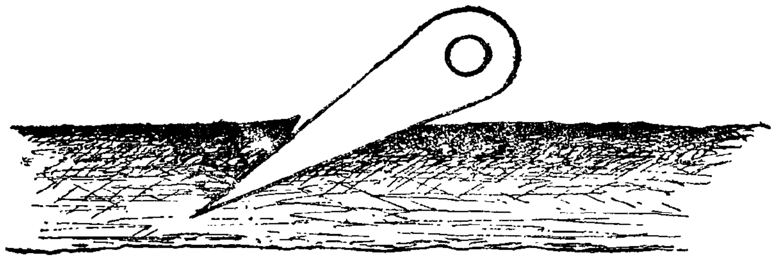

Fig. I—2 Obliquely driven axe.

The maintenance of axes as known to our woodcutters is crude, and consists in sharpening the axe blade by rubbing it against any stone available readily at site. This does not sharpen the axe blade properly, makes the axe inefficient, and causes undue strain to the worker. The proper sharpening of the axe can be done only on a revolving grinding stone.

Trimming axes.—Trimming axes are used for cutting of the branches of fallen trees and for rough-squaring timber. For the former purpose the blade is broader; for the latter a specially heavy axe, which may be as heavy as 4.5 kg (10 lb), is used.

For rough-squaring, these broad-bladed heavy axes are usually allowed to swing vertically, doing the necessary work of trimming the log by their own momentum. For this purpose they also have long handles, the length ranging from 110 to 140 cm (3½′ to 4½′).

Splitting axes.—Splitting axes, as the name implies, are used for splitting round logs longitudinally. Their action is thus almost purely a shearing one. They need not be very sharp, but should be heavy. The weight of the axe head should be principally distributed around the eye in order to give the axe the requisite driving power, and the blade should have sufficient taper.

Grubbing axes.—Grubbing axes (Fig. I—3) are intended for digging round and cutting through the roots of trees. The blade should be about 30 cm (12″) long, narrow and slightly curved, with the cutting edge 5 to 10 cm (2″ to 4″) broad.

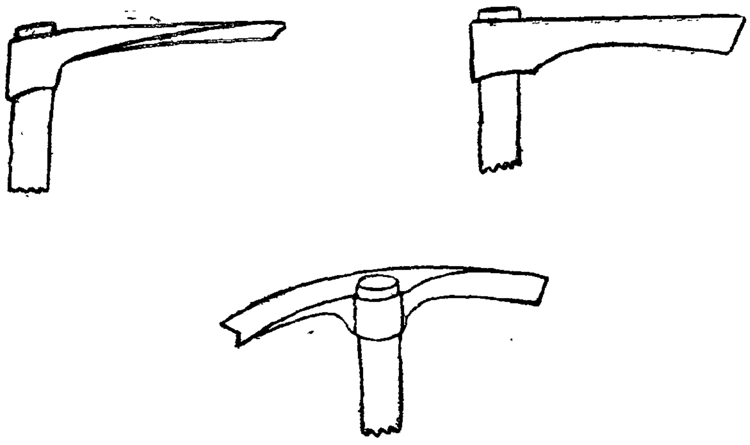

Fig. I—3. Grubbing axes (one-tenth natural size).

Bill-hooks may be mentioned here as tools used for felling bamboos and small poles and for cutting brushwood, though they are not strictly felling implements. They exhibit a great variety of shapes, each type being preferred in the locality where it is used. There are several tools in India which correspond to a certain degree to the European bill-hook, like the Nepalese *khukri*, the *dao* of Assam and Bengal, the *bakka* of Madhya Pradesh and the *darati* of Punjab and Uttar Pradesh.

Saws :

Deescription.—The saw consists of a blade toothed at one edge and one or two handles attached to the ends of the blade.

Saws are used for felling, crosscutting and ripping logs into planks, scantlings, sleepers and other classes of converted material. They are called two-handed or one-handed according as to whether they are intended to be worked by two men or one man. Only two-handed saws can be used for felling, except in the case of very small trees or poles. Most types of saws used for crosscutting felled trees into logs can also be used for felling, but the latter is much harder work, requiring considerable skill.

Saws were formerly made of iron, but all the best saws are now made of steel. Different saws are made for cutting softwoods and hardwoods, and the correct type of saw should always be ordered. The makers of such saws always have experts on their staff who can advise on such matters. The great advantage of saws over axes in felling and conversion is that they cause much less wastage of wood.

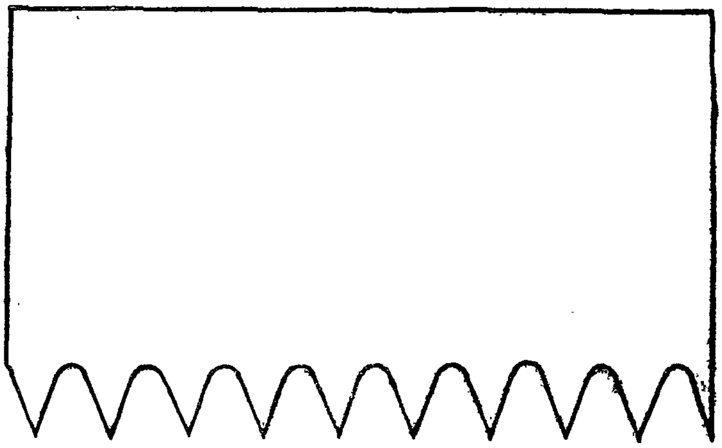

Fig. I—4. Crosscut saw—Peg-tooth form.

There are three popular kinds of saws used for felling and crosscutting, the M-tooth saw, the triangular or peg-tooth saw (Fig-I—4) and the lance-or raker-tooth saw (Fig. I—4). The latter is also known as the dog-or V-tooth saw.

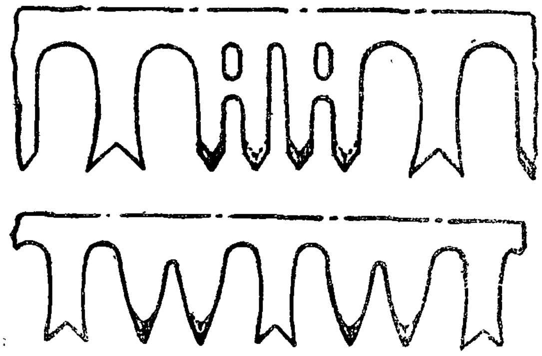

Fig. I—5. Crosscut saw—Raker-tooth form.

There are numerous different varieties of saws in the market, but they only differ in regard to the size, shape, weight, number of teeth and other minor details. Some definitions of the terms used in describing saws are given below :

The *face* of the tooth is that edge of the tooth which faces the cutting direction. The *back* of the tooth is the opposite edge; this does not apply to saws which cut in both directions.

The *space* is the distance from point to point of two adjacent teeth.

The *gullet* is the entire opening between two adjacent teeth.

The *pitch* of a tooth is the angle between the face of a tooth and the line passing through points of the teeth.

The *set* of the teeth is the extent to which the teeth are bent to either side of the plane of the blade.

The *gauge* s the thickness of the saw blade.

The *kerf* is the width of the cut made by the saw; it varies with the extent of the set.

Action of the saw.—The teeth of a saw act with a combined cutting and tearing action, the latter taking place more in softwoods than in hardwoods, as the loose fibres of softwoods are more easily torn. For this reason more sawdust is produced in the sawing of softwoods than in that of hardwoods.

Shape of the teeth.—Saws are used for crosscutting, that is cutting across the grain, and for ripping or cutting along the grain. In crosscutting saws, the teeth are made for cutting in both directions. The teeth are either two-edged, or alternate teeth have their faces on opposite sides. The teeth of crosscut saws are intended for speed and not accuracy. They are consequently large, and have a wide space and gullet, the latter being necessary to hold the large amount of sawdust produced in crosscutting. Ripping saws have small teeth. These saws usually cut in one direction only and are used where accuracy is required, as when scantlings and planks are sawn from a baulk. Whatever use a was is put to, it is important that the gullet should be sufficiently large to allow all the sawdust produced to collect between the teeth until each stroke is finished, as otherwise the labour is considerably increased.

Types of saws

Saws are of two main types ;(1) Crosscut saws, and (2) Ripping saws.

(1) *Crosscut saws.*—These may be either two-handed or one-handed the latter being used mainly for small work, as in the conversion of firewood and by carpenters. For work in the forest, two-handed saws are generally used. They vary considerably, mainly in the nature of the teeth, the more common types being the peg-tooth, the M-tooth, and the lance- or raker-tooth. The peg-tooth saw has exclusively teeth which are similar to one another and are triangular in form. The points and edges of the teeth cut and loosen the wood fibres, and the sawdust is pushed out through their gullets. M-tooth saws are fast cutting, but the American raker-tooth saw is the best in this respect. In this saw, the 'lance' or cutting teeth (two or four) alternate with Y-shaped teeth, called rakers. The object of the rakers is to chisel off the strip of wood lying between the two parallel cuts made by the sharp points of the cutting teeth, which are set and sharpened in the usual way. The rakers are not set, and as the cutting edge is at right angles to the sawing direction, they cut with the action of a chisel. This combination of two types of teeth results in the most efficient clearing of the kerf and very rapid cutting.

Modern two-handed crosscut saws have a convex cutting edge. This facilitates sawing by allowing for the swing of the arms, and leaves the whole of the cutting edge in contact with the surface of the cut at each motion without the sawyers having to assume a cramped position. In addition, it permits of a log being sawn through to the ground with greater facility. With a convex edge there is also more room for the sawdust, as the cut itself is straight though the saw is curved. Crosscut saws are now almost always made with detachable handles.

For crosscutting, the heavier the saw the better, for the weight itself will do much work. Crosscut double-handled saws vary from about 140 to 250 cm (4½′ to 8′) in length. In using such saws it must be emphasized that the force used must be a pull only. Inexperienced sawyers frequently try to push as well as pull, but this often results in saws buckling and breaking. Saws which break towards one end can often be converted into serviceable saws of shorter length by rivetting the handle at the broken end.

(2) *Ripping saws.*—There are three main types of ripping saws in common use in India for hand conversion of scantlings and planks;

(a) The frame saw

2—305 FRI&C/Dehra/82

(b) The Delhi saw

(c) The pit saw

Varieties of these saws can be seen in almost any bazaar in India and do not require any but a brief description.

(a) *The frame saw.*—This type (Fig. I—6) is extensively used for hand conversion and is a goo implement. It consists of a narrow blade set in a wooden frame to give rigidity. Blades of various lengths can be obtained. This is the universal saw in Himalayan forests.

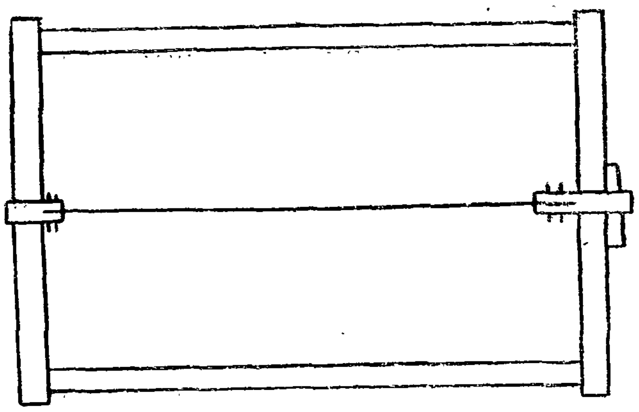

Fig. I—6. The Frame Saw.

(b) *The Delhi saw.*—It is also a common type. It has a peculiarly shaped curved blade (Fig. I-7), and can be used for crosscutting as well, as it is not set in a frame. It is used throughout the Uttar Pradesh for cutting sal.

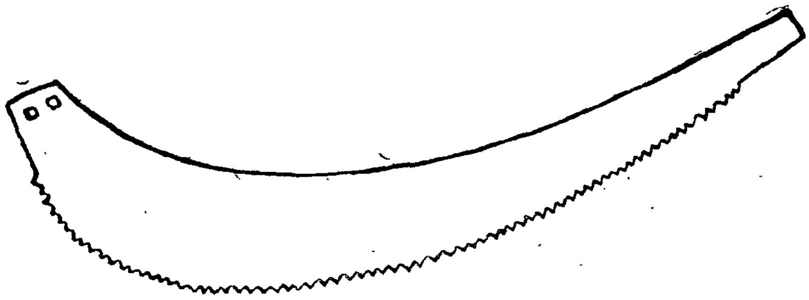

Fig. I—7. The Delhi Saw.

(c) *The pit saw.*—It is a long heavy saw (Fig. I—8) used when large logs are converted into beams; it is much in use in South India where sawyers are well-practised in its use.

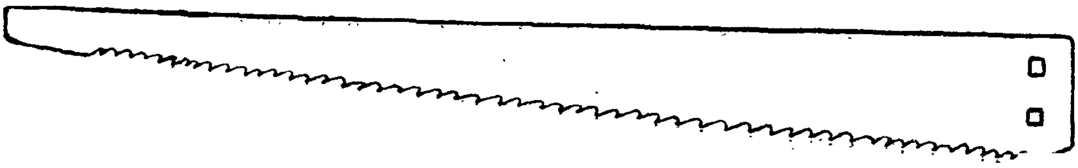

Fig. I—8. The Pit Saw.

Requisites of a good saw.—The blade should be stiff and elastic, springing back to its original shape if bent. It should be as thin and as narrow as possible but not too whippy. It should bend equally at all points. The blade should give a clear ringing sound when struck. To test the temper of the steel, one tooth should be sharply struck to one side with a hammer; if it bends too easily the metal is too soft, while if the tooth breaks it is too brittle. The saw should be well-balanced and the handles should be firmly fixed on the blade.

Care of saws.—When not in use, saws should be laid flat on the ground where they cannot be walked on to. They should not be hung up where they may fall or be knocked down. Saws should always

be greased to avoid rust. When stored in a godown, saws should be laid flat one on top of another on shelves, taking care that the blades are not resting unevenly.

Sharpening of saws.—If the cutting edge of the teeth of a saw are kept well sharpened, the efficiency is greatly increased. For saws which cut only in one direction, the cutting faces of the teeth should be filed alternately, one on one side and the next on the other side. As all saws used in the forest are 'set' it is always the inner edge of the face that is filed. In the case of crosscut saws, the teeth are filed on both faces, so that cutting is obtained in both directions. For crosscut saws, flat files are ordinarily used. For ripping saws, tapering triangular files are best, as the gullet is small. It is of great importance that filing should be done evenly on all teeth and that the teeth should be all of equal length. If the teeth are uneven, the short teeth do not work, while those which are too long are liable to have their tops broken off. Some firms have invented crosscut saws with perforated blades. The object of this is to ensure that the proper shape of the teeth will be obtained after repeated filing. No definite period can be laid down as to how often saws should be re-sharpened; this depends on how they are being looked after and on the amount of use they are being put to. Ordinarily, saws should be sharpened at the end of the day's work daily when in constant use. The cutting edges of the teeth should after filing be as sharp as knives The principles of filing are the same for all saws, viz., that all teeth must be kept very sharp, that tooth points must be kept on an even plane, that the set should be made even and equal in distance on each side of the saw, and that the gullets, which chamber the sawdust, should be kept well open and as near to the saw-maker's original pattern as possible.

Setting of saws.—If the kerf of a saw was of the same breadth as the thickness of the blade, the saw would stick fast and refuse to move. Hence it is necessary to make the kerf wider than the thickness of the blade. This is done by 'setting' the teeth. There are two methods of setting teeth, *spring-setting* and *swage-setting*. In spring setting, the teeth are slightly bent alternately to one side and the others this is the method used for all handsaws. In swage-setting, the teeth are wider at their tips than at the points where they join the blade; this form of setting is ordinarily used only in some machine-saws.

With regard to the amount of set to be given, this should never be more than double the thickness of the blade at the base of the teeth. A wider set is necessary for softwoods than for hardwoods. Sawyers usually set their saws by giving the teeth a sharp blow with the hammer, the correctness of the setting being tested by placing the saw on a flat surface such as an iron plate, with its edge bevelled to the proper angle. Various implements for setting saws are in use, and these are essential where valuable crosscut saws, such as the raker-tooth saw, are being used. In many places trained saw-filers are maintained. It is very important that each tooth should be given the same amount of set; if this is not done, teeth which are set too much wear down more rapidly and are liable to be broken off.

The techniques of proper levelling of the saw teeth, or *jointing* as it is called, and their filing and setting are not correctly known to our wood-cutters. The teeth in most of the saws in use will be found to be of different sizes and shapes. The faces of the teeth are never filed to a sharp edge, and consequently the action of the saw is reduced to simply tearing and shaving or, to use a simple and more expressive term, to rasping.

With saws not maintained properly, the production per hour is very low and even the cut is not straight; the sawyer has to overstrain himself and consequently gets fatigued in a short time. Lack of proper maintenance also reduces the life of a saw. It may be mentioned that for proper maintenance of a saw it is necessary to have a well-lighted working place and a suitable holder for saws.

Wedges (Fig. I—9):

Wedges are employed for splitting logs or fuel billets, and for assisting in the felling of trees and longitudinal sawing of timber. Wedges are made either entirely of iron or entirely of wood, or partly of iron and partly of wood. The iron wedge has either flat sides or sides with serrate grooves to prevent it from slipping out, as it is apt to if smooth. Wooden wedges are made of hard tough wood, and are sometimes strengthened by an iron band round the top. In a serviceable form of wedge, the lower part is made of iron and the upper part of wood strengthened round the top by an iron ring. Iron wedges

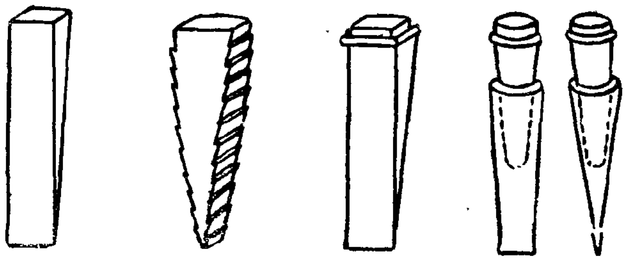

Fig. 1—9. Wedges (one tenth natural size).

1 & 2. Iron wedges 3. Wooden wedge with iron band
4. Wedges of wood with iron sheath

are driven in with a heavy wooden mallet, while wooden wedges are commonly driven in with the flat back of an axe. An improved form of iron wedge with wooden head is shown in Fig. I—12(e).

Improved Tools used for Felling and Conversion

Improved tools of Swiss origin have been recently introduced in India and are being used in some of the States in varying degrees. These are briefly described here.

Felling and trimming axes [Figs. I—10(a) and I—10(b)].—The cutting edge is of high quality tempered Swedish steel welded to the upper axe head of ordinary steel. The axes are fitted with curved wooden handles in oval-shaped eyes. The latter prevents the handle slipping round in the eye. The felling axe is slightly heavier than the trimming axe and has a long handle, the length of the handle being 70cm (28in.) for the former and 50 cm(20 in.) for the latter. The Swiss felling axe is generally heavier than the average Indian axe, the weight of the head varying from 1.8 to 2.0 kg(4 to 4½lb.)

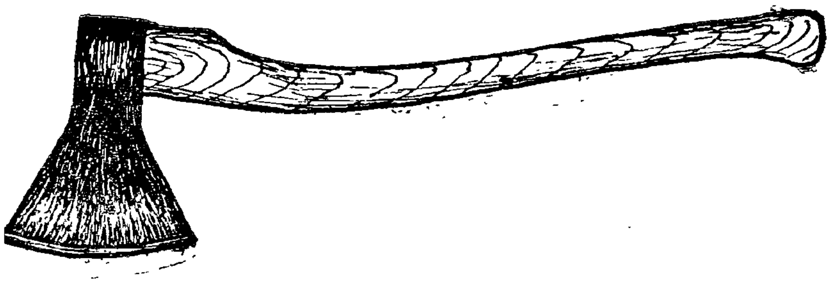

Fig. 1—10. (a). Felling Axe.

Fig. 1—10 (b). Trimming Axe.

Crosscut saws.—These have convex cutting edges and detachable handles. The latter permit the saw to be taken out of the cut without knocking out the wedges, which is often an advantage. This is particularly the case in hilly country where saws left in the cut when the tree falls are liable to get broken; with ordinary saws the fellers have no chance of removing the saw before the tree falls.

The saws are of the peg-tooth and the raker-tooth types. Their length varies from 165 to 220 cm and the width from 8.6 to 12.2 cm in centre.

Bow saws (Fig. I—11).—They have thin and narrow blades fixed to curved tubular steel frames and are very useful for a single man cutting up to 20cm(8in) diameter.

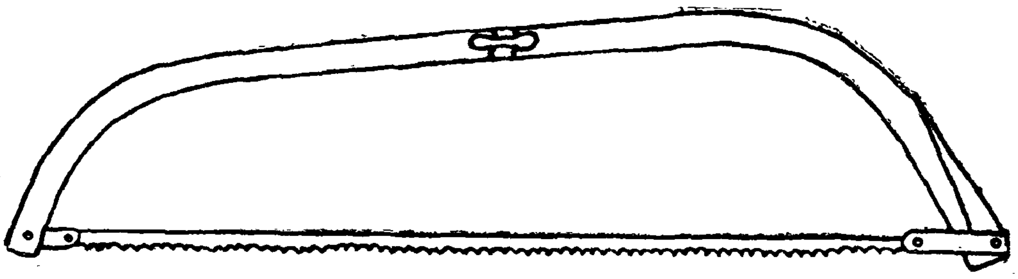

Fig. I —11. Bow Saw.

Cant-hooks and pickaroons.—These tools are used as lever in rolling, stopping and turning logs wherever required. The cant-hook [Fig. I—12 (a)] consists of a heavy wooden handle 1.5 to 1.8 m (5 to 6 feet) long with an iron hook hinged near its lower end which can be placed against the side of the log to give the leverage for rolling or turning it. The hook is pressed into the side of the log, and by applying hand power enough leverage is obtained to roll it.

In pickaroon [Fig. I—12 (b)] or zapi, as it is sometimes called, at the lower end of the wooden handle a recurved iron spike ½ m (1½ ft) long is fixed. The spike is fixed on the side of a log for pulling it up or down with hand power.

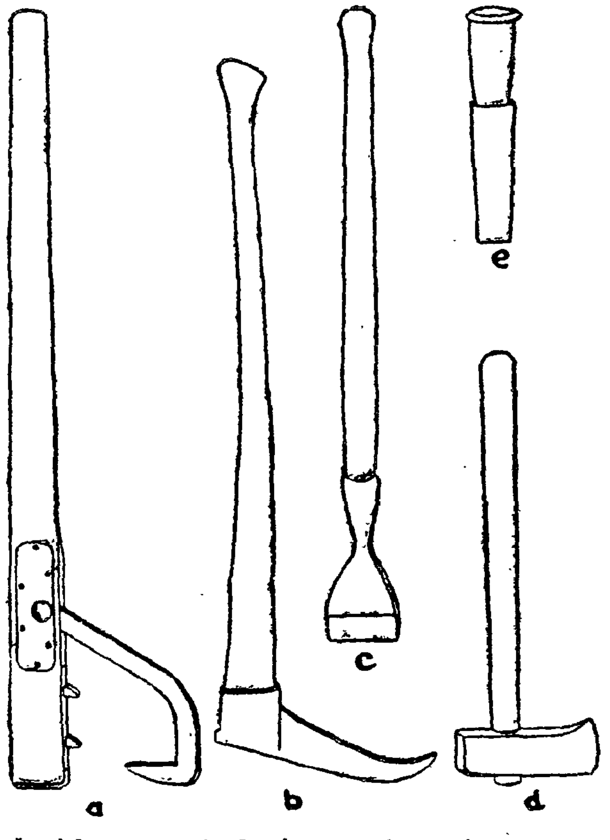

Fig. I—12. Cant hook, pickaroon and other improved tools (one-tenth natural size).

(a) Cant-hook (b) Pickaroon (c) Barking spade
(d) Cleaver (e) Iron wedge with wooden handle and iron ring

Barking spade.—This spade [Fig. I—12 (c)] is very useful for removing the bark from a felled tree while it is in green condition. It should be used with jerks holding the handle with both the hands. Such spades can strip off long lengths of bark in coniferous trees.

Cleaver.—One end of this tool [Fig. I—12 (d)] is made like an axe, whereas the other one is a hammer. The straight wooden handle is inserted in the middle in a circular eye, the weight of the head is 3.5 to 4.0 kg (7¾ to 8¾ lb). This tool is very useful for splitting firewood and driving in wedges, as also for other purposes where a sledge-hammer is required.

Measuring stick (Fig. I. 13).—While crosscutting the tree into logs, it is important that correct lengths are cut. A metre-long wooden stick made of seasoned timber is used for the work. One end of this stick has an iron hook attached to it, and the other a recurved iron spike for giving a scratch on the log.

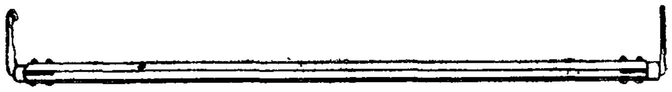

Fig. I—13. Measuring Stick.

Cable-tensioner or cable-puller.—During felling operations the need for exercising a strong pull is often felt. This is especially the case when leaning trees are felled in a direction away from their lean, or when one has to avoid the felled stem getting entangled in other trees, or in order to bring down entangled trees. The cable-tensioner or cable-puller (Fig. I—14) is a simple and effective apparatus developed in Switzerland to serve this purpose. With this apparatus, two or three men can exercise a pull of 3.5 tonnes.

The cable-puller (Fig. I—14) consists of a two-sided lever which is operated by a thin pole inserted in it On each side of the lever, a movable arm is fitted with a cable clamp. In this way,

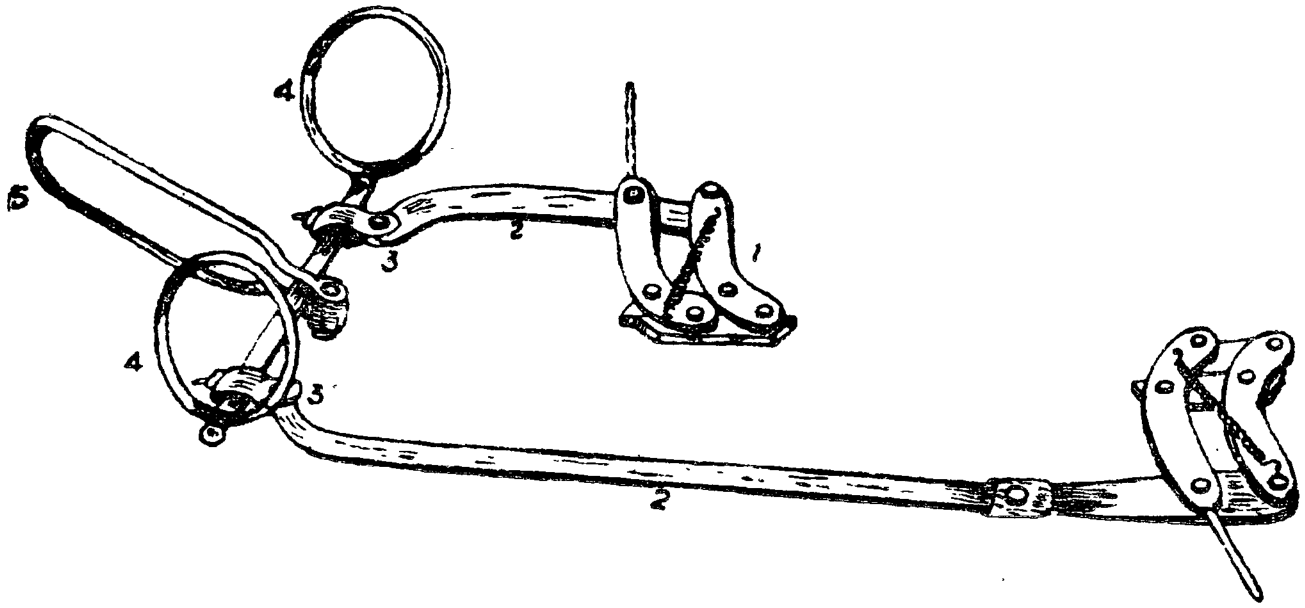

Fig. I—14. The Cable-Tensioner (or Cable-Puller).

1. Cable clamps 2. Steel arms 3. Hinges
4. Rings for holding the lever 5. Fastening hook

three different lengths of the lever arm corresponding to three different lever ratios can be adjusted. The cable clamps work alternately and open and close automatically. As one clamp loosens and moves up the other holds the rope tight, and *vice versa*. These clamps work like the two arms of a person pulling a rope. For pulling or tightening a cable, one to three men operate the wooden pole and another man pulls the cable lightly behind both the clamps, thus making it easier for the open clamps to fall back. The cable-puller is suited for wire ropes of 8 to 11 mm diameter and weighs about 16 kg.

A cable is fixed at two-thirds the height of the tree with a spiraloid hook. This cable is then passed through a pulley tied on to another tree in the direction of fall and the cable, after changing its direction on passing through the pulley, is taken to the cable-puller and fixed in its two cable clamps. The cable-puller equipment is itself fastened with a cable to another tree, safely away from the direction of fall of the leaning tree to be felled. When tightened, the cable-puller can develop a pull of 3.5 tonnes.

After the equipment and cables are fixed, the usual felling cuts are given and necessary tension is applied to the cable.

Stem-tightener (Fig. I—15).—This consists of a 13 mm wire-rope cable which is put around the stem, just above the felling cut after removing the bark, and tightened with the help of a lever mechanism in the equipment. It is used to prevent the butt ends of trees, especially leaning ones, from splitting during felling, thus saving the most valuable part of the tree.

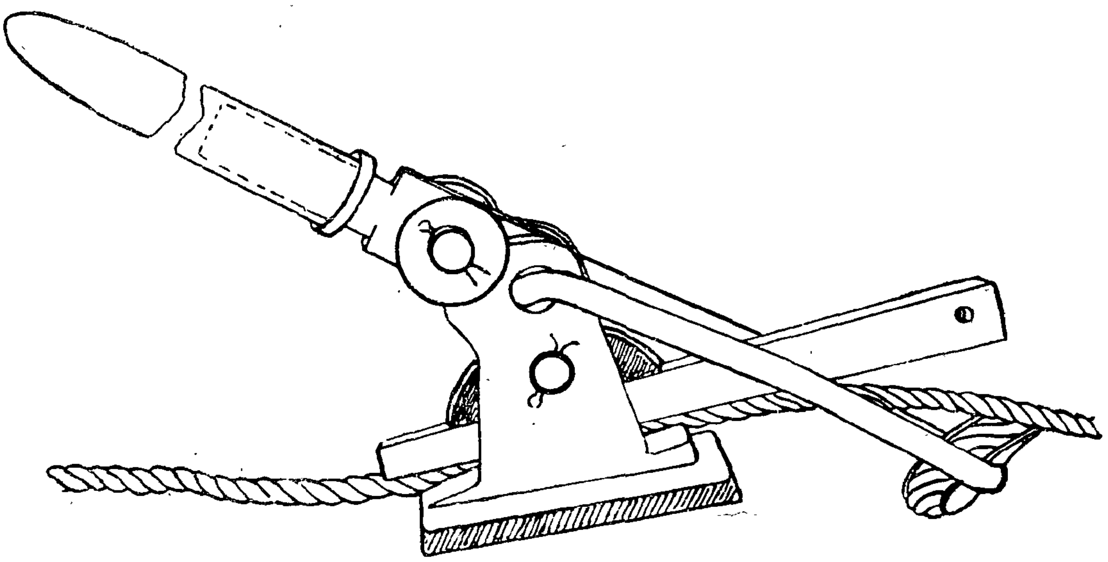

Fig. I—15. Stem-tightener.

Safety-belt and crampoons.—This equipment has been designed for safe climbing of trees for lopping the branches, topping of spar trees, fixing cables for cable-pullers, fixing intermediate supports for skyline crane installations etc. high up on trees, and similar other purposes (Fig. I-16). The crampoons (also known as climbing irons) are fastened to each foot of the climber and the belt is put around the waist with straps on shoulders. This belt has two cables passing through special locking devices on either side of it for the adjustment of cable lengths. The cables can be pulled back through these locking devices, but they cannot be pulled forward to the front unless the locking device is released.

One cable is used at a time. It is passed around the stem and its free-end clip is fixed into the hook provided on the other side for the purpose. The length of the cable can be adjusted as convenient. The pair of crampoons have a protruding iron nail on the inner side. These nails are dug into the bark while climbing to give support to the legs, and the cable thrown round the stem is moved up as one climbs on the tree. The branches are lopped with a small axe or a pruning saw on the way up as both the hands of the climber are free.

The other cable is used while crossing a big branch on the bifurcation of the main stem. As the climber stands poised on one cable below a branch, the other cable is pulled out and thrown over the branch and its clip taken to the hook on the opposite side of the belt and fixed in it. The first cable around the main stem and below the branch is then released from its hook as the climber is supported by the other cable put around the branch. The climber then puts the free cable again around the main stem after crossing the branch, releases the other cable put around the branch, and then continues his climbing along the main stem after crossing the branch.

• *Power chain saws.*—Chain saws operated by petrol or eletricity are being increasingly used in the western countries (Fig. I—17). In the U. S. S. R. they have almost completely replaced axes and manual saws for felling and cross-cutting. These saws are efficient, but require good care and maintenance. They are rather difficult to carry over rough terrain, especially when trees to be felled are scattered over a large area. Moreover, in remote areas repairs and replacements cannot be readily arranged for. Power chain saws are not much in use in India.

Season for Felling

In India, the season for felling is mainly determined by climatic conditions. In the Himalays, above an elevation of about 1,800 metres, snowfall is generally heavy during the winter and felling is usually done from March onwards, all forest work being suspended during the cold months. In some parts of Jammu and Kashmir State, however, local labour being accustomed to the felling of trees during winter, felling operations are carried on even during the cold months. In European and North American countries, where long winters with snow occur, work is continued throughout the year. In these countries dragging of logs on snow, directly as well as on sleds, is the usual practice, the snow actually faciliating transportation. It is not advisable to fell trees during the rains on very

steep slopes, owing to the danger of accidents and the chances of erosion by the logs sliding on soft earth and scouring channels in the ground. In addition, sliding logs may do considerable damage to the forest they pass through and to themselves. Trees can sometimes be saved from being broken on bad ground by felling them in early spring into depressions and stream-beds in which drifted snow is still lying deep. In the plains and submontane tracts of India, the working season is chiefly confined to the cold weather, that is from October to March. During the hot weather there is always the danger from fire, and water is often unobtainable. Felling in these places, therefore, begins as early as possible after the rains, so that conversion may not be delayed and the coupe may be cleared before the next hot weather begins. In some places felling during the rains may be possible, and this is all to the good where it can be done. In other cases, trees can be lopped, if lopping has to be done in the previous winter, so that only the actual felling remains to be done when the rains are over.

The question as to whether winter or summer felling is preferable from the point of view of the effect on the quality of the timber, is one which has for long been debated. it is not of great importance as it concerns mainly the sapwood, but it is probable that winter felling, when the trees are at rest, is the more favourable. From the point of view of seasoning, it may be taken as a rough rule that felling in very hot dry wheather is harmful, as the logs dry too rapidly and this results in splitting and cracking. In the case, however, of such species as are liable to rapid fungus attack, rapid dryinge may be an advantage; felling them in warm damp weather is to be avoided. Coppice should be felled during the period of rest. This leaves a full growing season ahead for the young shoots to develop—an important point in localities where frost occurs.

METHODS OF FELLING

General rules

The felling of trees is an art which is unfortunately not sufficiently understood in India. It must be made clear, to begin with, that economic conversion begins with the felling of the tree. However excellent subsequent conversion may be, it cannot entirely make up for the loss of timber resulting from faulty felling. All persons in-charge of felling operations should be conversant with the theory and practice of felling trees and should have some knowledge of how to use and maintain axes and saws. Good felling requires skill and it is not a good policy to employ a set of local villagers merely because they possess axes and can cut down trees. The best plan is to keep permanent gangs of trained fellers who can go round the felling areas year after year. If not already trained, they must be taught what is required of them, and both they and the Forest Department will benefit considerably by a little initial instruction. This practice can of course be followed only where departmental felling is done, but even in cases where felling is done by the purchasers, it is beneficial to all concerned to see that felling in done in the best possible way.

There are two main principles underlying all methods of felling ;

(1) The production of the maximum amount of sound timber that can be made available for export from the forest.

(2) The avoidance of damage to the surrounding forest.

In order to satisfy these conditions the following rules must be observed.

(a) *Trees should be felled as near the ground as possible.*——This important rule is to prevent waste of timber, and is of primary importance in the case of valuable timbers such as teak.

(b) *Trees should be felled in a manner and in the direction in which they will do least damage to themselves and the surrounding forest.*——As example, trees should not be felled across others lying on the ground. They should not be felled across boulders or sharp depressions or spurs. On hilly ground it is best to fell trees uphill, since in this direction they have the smallest angle to fall through and will fall parallel with the lie of the round. To do

Fig. I—16. Tree climbing with safety belt and crampoon.

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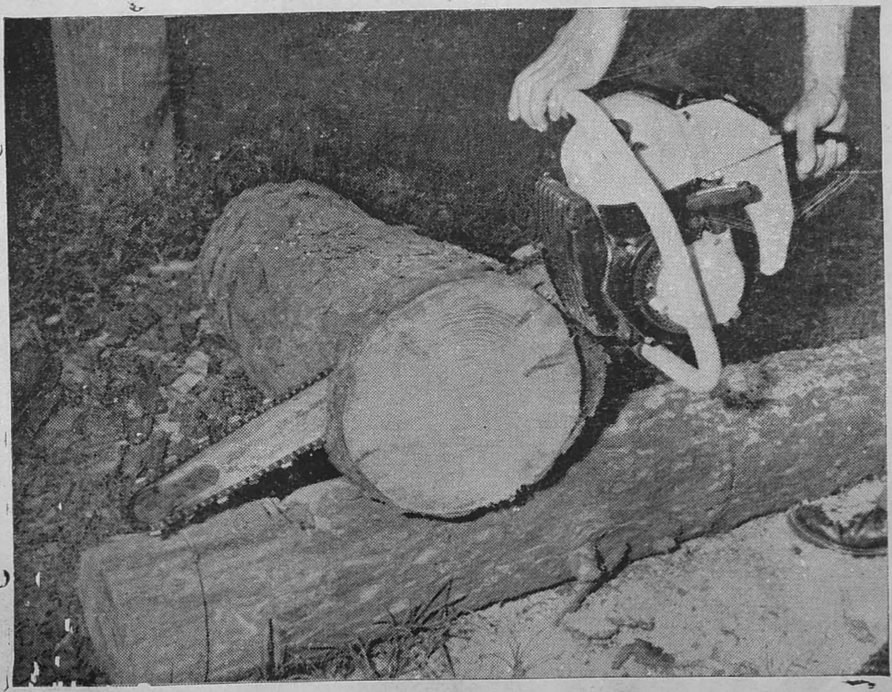
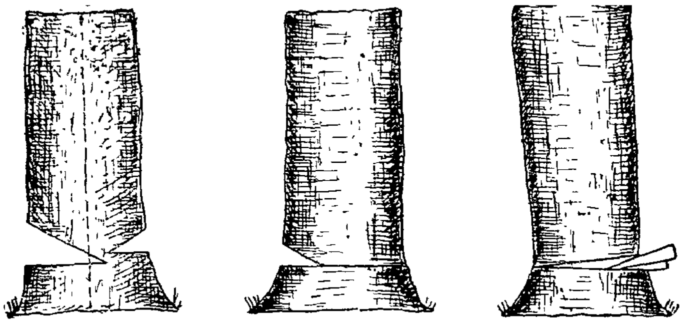


Fig. I—17. Power chain saw (in action).



(a) (b) (c)

Fig. I—18. Methods of felling.

(a) Felling with axe alone. (b) Felling with axe and saw combined.
(c) Felling with saw alone.

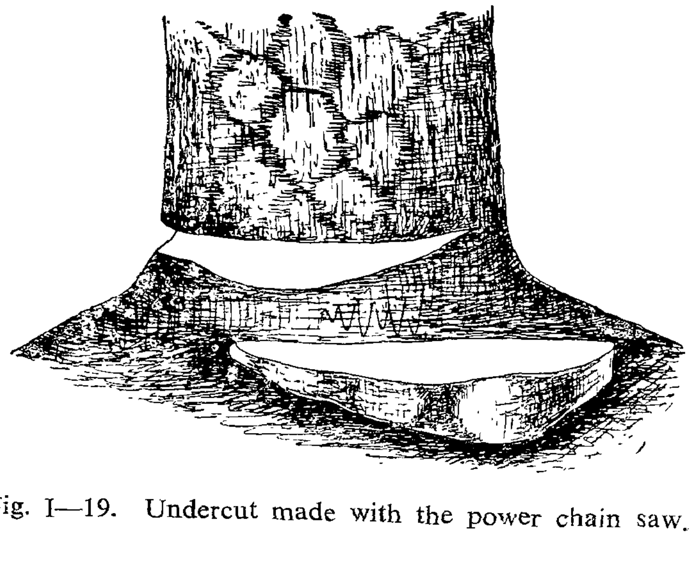


Fig. I—19. Undercut made with the power chain saw.

this requires skill, more particularly as trees on hillsides tend to lean outwards and are generally more branchy on the lower side, thereby increasing the tendency to fall that way. Under these circumstances, trees have first to be lopped, and the fall directed by using a rope or a cable-puller. Expert axemen in parts of the Himachal Pradesh can fell large deodar trees on steep ground in such a way that the butts rest on the stumps after the trees have been felled in an uphill direction. Where this cannot be done felling should be made in vertical strips and the trees felled herring-bore fashion. If this is done, these felled trees that start sliding or rolling are held up by the standing ones.

Felling along the contour in undulating ground results in the trees breaking their backs and in grest damage to the timber. Sometimes it is even best to fell trees only downhill, in which case no lopping should be done as the branches act as a brake. Although the top of the tree may be broken it is sometimes possible to save the valuable butt log in this way. Felling downhill should, however, be resorted to only under exceptional difficulties.

(c) *Trees should not be felled such that they fall into a place where it is not possible to convert or extract the timber.*—If this rule cannot be complied with, it is better to leave such trees standing. Similarly it is not worth while felling trees which are bound to be smashed to pieces in falling even when their removal is silviculturally desirable.

(d) *Trees should be felled in a manner and in a direction in which they will do least damage to the surrounding crops.*—Whenever there is danger of young growth being damaged by felling, as in regeneration areas and selection forests, trees should be lopped before being felled; the extra cost will always be worthwhile. A good plan is for the marking officer to have a special sign blazed or written on each tree that he considers should be lopped. Climbers should be cut at the time of marking.

(e) *Trees should not be felled during a strong wind.*—During a strong wind it is not possible to ensure that trees will fall in the required direction: the work is exceedingly dangerous and should not be allowed.

(f) *Felling should usually begin at the top of a slope and proceed in a downward direction.*—If felling begins on the upper slopes of a forest, any trees which start sliding down are more likely to be held up by the stems below, as the lower part of the forest will not have been thinned out. If as is generally the case conversion follows close upon felling, by starting felling at the top there will be no danger of trees sliding down and damaging previously felled trees, stacks of converted timber or even the sawyers themselves, as would be the case were felling to start from the bottom.

(g) *Felling should be concentrated as much as possible.*—As a rule, it is advisable to divide the felling area into sections and to distribute these amongst the various felling gangs, so that the work may be kept under better supervision and not allowed to proceed in an uncontrolled way all over the forest. As a general rule, conversion should keep pace with felling; in attention to this point enhances the danger from fire, theft and insect attack and as most species are best converted green there is an additional incentive to avoid leaving logs lying in the forest for long periods.

Felling with axes and saws :

There are three important methods of felling a tree :

(1) With the axe alone.

(2) With the saw and sex combined.

(3) With the saw alone.

Felling with axe and saw is mostly confined to Jammu and Kashmir, Punjab, Himachal Pradesh, and Uttar Pradesh, whereas felling with axe alone is still the common method employed over the greater part of other States. Felling with saw alone has not been in vouge in India but a beginning has recently been made to introduce it in north-western Himalayas.

In felling with an axe alone [(Fig. I—18 (a)], an undercut is given with the axe on the side to wards which the tree is to fall and this cut is carried through about two-thirds of the diameter of the tree. In big trees this undercut may be extended to as much as three-quarters of their diameter. In this method the centre of gravity of the tree is cut through by the undercut. The felling cut is then made exactly opposite to this cut about 10 to 15 cm (4" to 6") above it. Both cuts must be parallel to each other, otherwise the fall of the tree would deviate from the desired direction.

This method is wasteful and should therefore be discouraged as far as possible.

While felling with axe and saw combined [Fig. I—18 (b)], a cut extending to about one-fifth or one-fourth of the diameter of the stem is first made with the axe on the side to which the tree is intended to fall. A saw cut is then made on the opposite side and is continued to meet the first cut, wedges being driven in as the sawing proceeds. This method is the most satisfactory as the direction of fall is easily controlled and a considerable portion of the butt log, which is the most valuable part of the tree, is saved.

When felling with the saw alone [Fig. I—18 (c)], the saw cut begins on the side opposite to that to which the tree is intended to fall, and is continued right across the tree. Wedges are driven in behind the saw as the cutting proceeds so as to prevent the saw from sticking and to guide the fall of the tree. This method involves the least wastage of wood, but the fall of the tree is difficult to guide as the tree in falling rests on the rounded edge of the stump and is apt to roll to one side. This method is seldom used in India.

Provided the centre of gravity of the tree is on the stump, the tree can be felled in any desired direction by manipulation of the cuts and the wedges. If the centre of gravity is outside the stump, the tree can be swung through an angle of 30°—45° by manipulating the cut. To attempt to fell a tree, in a direction opposite to that in which the centre of gravity falls outside the stump, is quite impossible without the help of a rope or modern cable-puller equipment.

In western countries, the usual practice is first to make the lower part of the stem close to the ground cylindrical by removing buttresses, root-swells, etc., with the trimming axe. This makes sawing easier and saves considerable work for the sawmills in removing these protrusions. Moreover, the desired direction of fall can be adhered to better and the cylindrical stem can be skidded more conveniently. The stem is also barked upto a length of 1 metre or so, since barking is easier while the tree is standing. The tree is then felled using more or less the same technique as described for felling by axe and saw, with the difference that the undercut is also made with the saw. The use of power chain saw has made possible an undercut (Fig. I—19) being taken from the stump portion, rather than from the butt as is usual when felling with an axe and crosscut saw, thus saving some of the best timber in the butt log. This type of undercut is also possible with an axe but not with a handsaw.

Leaning trees are felled in a direction other than that of the lean with the help of cable-pullers. Stem-tighteners are used to prevent splitting of the stems while felling leaning trees.

Felling by the roots

Under certain conditions, such as where a road alignment has to be cleared or where the ground has to be cleaned for plantation work, it may be necessary to uproot trees. It is a slow process, except in sandy soils, but it allows of the most complete utilization of the tree. The ordinary method consists in digging the earth away from the roots, which are then severed with an axe as they become exposed. The fall of the tree may be accelerated by the use of a rope or a cable-tensioner.

Felling by the roots is always desirable in the case of very valuable trees. Sandal (*Santalum album*) is a case in point, where roots down to the size of half-a-rupee are extracted for the oil they contain. Khair(*Acacia catechu*), the roots of which are rich in cutch, is another example.

Many mechanical devices like winches have been invented for uprooting trees, but they have not yet become popular in this country.

General precautions in felling

(i) Two wood-cutters should not be allowed to work at the same time on one tree with separate axes or saws. This often results in the outer (felling) cut and inner cut (undercut) being of the same size, so that all control over the direction of fall is lost. Only one wood-cutter

should work on one tree; with very large trees, however, two wood-cutters may work on the same cut but not on opposite cuts.

(ii) Roping and lopping should be done wherever necessary. A cable-tensioner should be used for felling leaning trees when they are to be felled against the direction of their lean.

(iii) The felling direction should be correctly decided on before undertaking the actual felling operation, to avoid damage to the adjoining trees and the regeneration and prevent the felled tree lodging on other trees.

(iv) The wood-cutters should plan their 'getaway' before hand for their safety.

(v) Saw or other tools should not be left near the stump, while the tree is falling.

(vi) If the tree is leaning towards the intended direction of its fall, then the splitting of the butt-end of the stem, which destroys most valuable portion of timber, can be prevented by using a stem-tightener if available, or by 'sawing off the corners'.

(vii) Lodging of a falling tree over another adjoining tree must always be avoided. If, however, the fallen tree gets entangled or lodged over the adjoining tree, then it should be got freed with the help of a cable-puller by pulling its cut end away.

(viii) Timely warning should be given to the labour working near about when the tree is about to fall.

Safety Measures in Logging

Logging is one of the most dangerous occupations and accidents causing injuries and fatalities are frequent. These result not only on human suffering but also in economic loss to the injured and their families as also to the employers. Every effort should therefore be made to minimise the frequency as well as the severity of accidents. This can be done by constant training and propaganda till safe methods for each operation become a second nature to the worker. Improved tools and equipment should be used so as to lighten manual effort and thereby minimise the chances of accidents.

Conversion

General remarks

The conversion of trees in the forest implies the preparation of timber to meet the demands of all classes of markets whether local or distant. 'Conversion' itself is generally taken to mean the process of producing sawn timber from the log.

A rough classification of timber in the commercial sense is as follows :

(1) Timber in the round, or logs.

(2) Roughly converted timber, or timber squared with the axe, usually called baulks or rough squares.

(3) Sawn timber, such as squares, beams, sleepers, scantlings and planks.

The choice between conversion into round timber or sawn timber depends on a number of considerations, the more important of which are :

(1) *The demands of the market.*—In some localities the whole outturn may be saleable in the form of round timber. In others the demand for logs may be small, or be restricted to some special industry, e.g., match or pulpwood manufacture, or the production of some special minor forest produce such as cutch and *katha.*

(2) *Availability of skilled labour.*—In many localities skilled sawyers cannot be found in sufficiently large numbers; sometimes the localities may be too remote to make importing sawyers worthwhile. It is usually easier to obtain labour for crosscutting into logs, or bucking as it is sometimes called, than for conversion into sawn timber.

(3) *Sawmills.*—Erection of sawmills may be justified if the forests can produce a large and sustained yield of wood of species for which a market exists, and in that case extraction would be in the form of logs for conversion in the sawmill. Portable sawmills can also be set up in or near the forests if roads exist for the transport of such sawmills up to the site.

(4) *The topography of the country.*—This is a dominant factor to be considered at the very outset of any extraction scheme, together with the length of lead and the available methods of transport. In any extensive scheme in hilly country, it becomes necessary to work each valley or similar topographical feature as a separate extraction unit, which should be completed before the next adjoining tract is entered. Hilly country generally requires elaborate extraction measures and engineering skill to transport the produce without damage. Thus the species that can be extracted with profit become correspondingly limited in number. Sawing at stump site is frequently resorted to, and the sawn produce transported by manual labour to the nearest carting, cable-hauling or floating depot. In the plains, extraction and transport present few difficulties, but in more difficult and remote localities a careful prior assessment, both of forest potentialities and of the cost of production as at the sale depots, is essential for any proposed scheme of operations.

(5) *Damage to the forest.*—With conversion into sawn timber at stump-site, large accumulations of slash and refuse are left in the forest, and these entail danger from fire and insanitary conditions, except in cases where demand exists for scrapwood as fuel. Log extraction may have a beneficial effect, as the soil is wounded during extraction and a minimum of refuse is left behind. Sawing at stump site is wasteful, and should therefore be resorted to only when unavoidable. As far as possible, the tree should be extracted from the forest in log form and converted in a sawmill for fuller utilization.

Crosscutting felled trees

After felling, limbing (that is, trimming off the branches and excrescences from the felled tree) and, if required, barking, the stem is crosscut into logs. The latter process is also sometimes termed as *bucking*. (It has for long been known in India as logging, but this term has now acquired a comprehensive meaning, covering all phases of timber extraction). The lengths of the logs to be cut will depend on the market requirements and the method of, and facilities for, transportation. For example, there is a limit to the weight of a log which can be dragged by animals, or the size and condition of a floting stream may be the limiting factor.

Log lengths should be marked off beginning from the butt-end unless, owing to rottenness in the lower part or crookedness in some part of the bole, more economic conversion can be effected by starting elsewhere. Crosscutting should always be done with the saw, as crosscutting with axe is a wasteful practice.

Where logs have to be dragged or extracted down slides or chutes, it is usual to trim the ends so as to prevent the front end of the log stubbing into the ground during extraction. Where logs have to be dragged, a common practice is to round off that part of the end on the side of the log which gives the best sliding surface. This is called *snouting*. Where sliding is contemplated, as in most hill forests, the whole of the end is rounded off. This is called *snipping*. Unnecessary trimming of any log should be avoided as it leads to waste.

If drag-holes have to be cut in logs, waste can be avoided by crosscutting the top log such that it includes the base of a branch in which the drag-hole may be cut and not in the log itself. Similarly, if a tree is crooked, the greatest length of undamaged straight timber is obtained by crosscutting a few centimetres into the bend, and cutting the drag-hole in the curved portion. It is better to use choker ropes (cables with a hook at one end fastened round logs; see Fig. II-I under Chapter II) for dragging logs. This will make drag-holes unnecessary and eliminate the waste on that account.

A careful record of all converted timber must be made before it leaves the jurisdiction of the extraction unit, generally a forest range or division. For example where transportation is by water, it is usual to assemble all the logs at the launching depots first. Methods of recording output may vary considerably, but the general procedure is to give each log a serial number, which is deeply carved into the log by means of a chisel. Any other marks which may be prescribed, such as the year of conversion, property mark, etc., are also made at the same time. All the logs are then measured, and the measurements, together with the serial numbers, are entered in list or registers. In some depots, logs may have to be sorted and classified for sale or royalty purposes. As an

illustration of log classification, the classification as adopted for a few important depots is given in Appendix VII.

Description of converted wood

The nomenclature of converted wood varies but, broadly speaking, the following are the most common terms used:

(1) Squares or baulks. These may be with or without wane.
(2) Beams. Usually rectangular and free from wane.
(3) Railway sleepers.
(4) Scantlings. Square or rectangular.
(5) Battens.
(6) Planks.
(7) Slabs.
(8) Poles.
(9) Firewood.
(10) Pulpwood.

These terms are usually open to wide interpretation and are overlapping; in practice each market has its own sizes and names. To lay down any hard and fast classification of converted material is therefore no easy task. Every forest officer should, however, make himself acquainted with the demand and markets of his own locality.

Rough conversion in the forest

Timber can be squared in the forest by means of an axe into baulks or rough squares, when a special demand exists for this class of produce or when it is necessary to reduce the weight of timber to fasilitate transport. Rough squaring is usually done in the Himalayan forests. This is, however, a wasteful process and should be avoided as far as possible.

Hand-sawing

In India, conversion of trees in the forest by hand-sawing is the most extensively used method. It is often the only possible method of conversion. Conversion in the forest may not, however, be the last stage, for some of the larger sizes such as sleepers and beams converted in the forest may, after being sold, be re-sawn into planks, etc., before being finally utilized.

The fundamental object of all conversion methods is the production of the largest outturn of the best quality timber. Further, economic conversion aims at converting the trees in such a way that the maximum quantity of the more valuable sizes is produced. Some sizes generally fetch higher rates per unit volume in the market than others, and it can be taken as a general rule that unless this has been taken into consideration, the tree has not been converted to the best economic advantage. This implies a knowledge of how to convert a log to the best advantage, a matter which can only be learnt from prolonged practical experience and is often neglected as being the job of the sawyer and not of the forest officer.

Description of hand-sawing of scantlings, etc.—After trimming off the branches the felled tree is crosscut into logs of appropriate lengths. Taking the thin end of the log, the timber sizes to be obtained by conversion should then be 'laid out', i.e., marked on the thin end of the log, after which the log is squared either with an axe or a saw to conform to the timber sizes laid out. The wood at the centre of a log is, as a rule, specially liable to decompose quickly and to warp and split. Therefore, in marking off logs for sawing, every effort should be made to avoid including the heart centre in any kind of beam or scantling; this is specially to be avoided in railway sleepers, as the railways do not accept such sleepers. Small trees capable of giving only one scantling of sleeper section 26 cm × 13 cm (10" × 5") should, therefore, never be converted into railway sleepers. If a line is drawn through the centre of large logs before squaring, it is generally possible to obtain exactly the same number of scantlings devoid of this defect as would be possible without so eliminating the centre. This necessitates marking the layout of the timber sizes on the end of the log before squaring, and then adjusting the squaring of the log to

the layout. The reverse procedure is often seen in practice, but this should be rigidly discouraged. It is a very common practice to get a log squared first without any regard to what is to be sawn out of it, with the result that timber is wasted and inferior grades are produced. It must be emphasized that all persons engaged in this work of marking off and squaring should make themselves competent in all details. The procedure is that on the two ends of the log the lines delimiting the cross-section of the desired baulk are first ruled. Then the longitudinal lines along which the slabs are to be trimmed or sawn down are marked. If the log is to be axe-squared, the *mistri* stands upon it and, beginning at one end, moves down it, cutting off the outside slab with a heavy trimming axe up to the line, with downward swings of his axe. As each side is completed, the log is rolled over and another side trimmed. If squaring is done with the saw, the log is rolled over a pit, one man working in the pit, the other standing on the log. These different methods are matters of local custom and usage and cannot be easily changed. Careful and accurate squaring is of great importance, and inexperienced *mistries* should not be engaged. An advantage of saw-squaring is that it is more economical because the side slabs are available for sale where there is a demand for them.

The squared timber is now ready for conversion into the sizes required. The cross-sections of the scantlings to be cut have already been roughly marked out on the thin end of the log before squaring. They are now fully marked off, using a ruler, and the external longitudinal lines which the saw-cuts are to follow are shown by tightly stretching a string blackened with wet charcoal powder or other colouring agent. The string is held firmly at both ends and then pulled away from the timber at the centre. On being let go it springs back and leaves a straight black or coloured line as it strikes the wood. The baulk is then usually propped up at one end and sawn down along the lines into the sizes required, one man working from underneath, the other standing on the log.

Trees or logs which are too small to be sawn into scantlings are often converted by trimming with the axe into long timbers of square section. This class of timber often finds a ready market with the local villager for house-building. Another popular form of scantling for the same purpose is made by cutting small logs into four equal pieces, each piece having two sawn sides and one round side. Small-sized sal is often axe-dressed into round *tors* (billets).

In all departmental extraction the felling, bucking and sawing must be carried out under definite written instructions as to the manner in which every part of the work is to be done, the sizes and the numbers of each size to be sawn, and the method of passing and control.

Sawing of railway sleepers

The sawing of railway sleepers is one of the biggest items of timber conversion in this country. The sawing is usually done by hand, and only in a few instances by machine.

The actual sizes of sleepers used in India vary considerably, especially in regard to length, but the standard sizes for different gauges are as follows :—

	Gauge	*Standard Sleeper Size*
Broad Gauge	167.64 cm (5′ 6″)	...275 cm × 26 cm × 13 cm (9′×10″×5″)
Metre Gauge	100.00 cm (3′3⅜″)	...183 cm × 21 cm × 12 cm (6′×8″×4½″)
Narrow Gauge	76.20 cm (2′ 6″)	...153 cm × 18 cm × 12 cm (5′×7″×4½″)
Light Narrow Gauge	61 cm (2′)	...153 cm × 16 cm × 11 cm (5′×6″×4″)

In addition to the above size, there are 'special' sizes sleepers for bridges and crossings. These are not always of standard sizes, but vary according to requirements.

In practice, it is customary to cut sleepers about 0.6 to 1.2 cm (¼″ to ½″) larger in width and thickness, and a few centimetres longer than the required size in order to allow for loss in shrinkage.

The form and size of the tree have the greatest bearing on the output of sleepers.

Fig. I—20 illustrates the most economical sizes of logs for cutting sleepers, and shows the maximum number of Broad Gauge sleepers which can be cut from trees ranging from 35.6 to 76.2 cm (14″—30″) in diameter. It will be seen that the difference of a few centimetres in diameter makes a con-

siderable difference, throughout the whole series, in the number of sleepers which can be sawn from a log.

Some interesting records are available on the subject of the number of sleepers cut from large trees. In one case a sal tree in Assam with a girth of 3.48 m (11'3") gave no less than 142 M.G. sleepers, while another tree in the same locality with a girth of 2.57 m (8' 5") gave 111 M.G. sleepers. Another case of unusually large production is on record where ten trees gave 782 M.G. sleepers, which makes an average of 78 sleepers per tree. It is seldom, however, that such large timber-yielding trees are found nowadays.

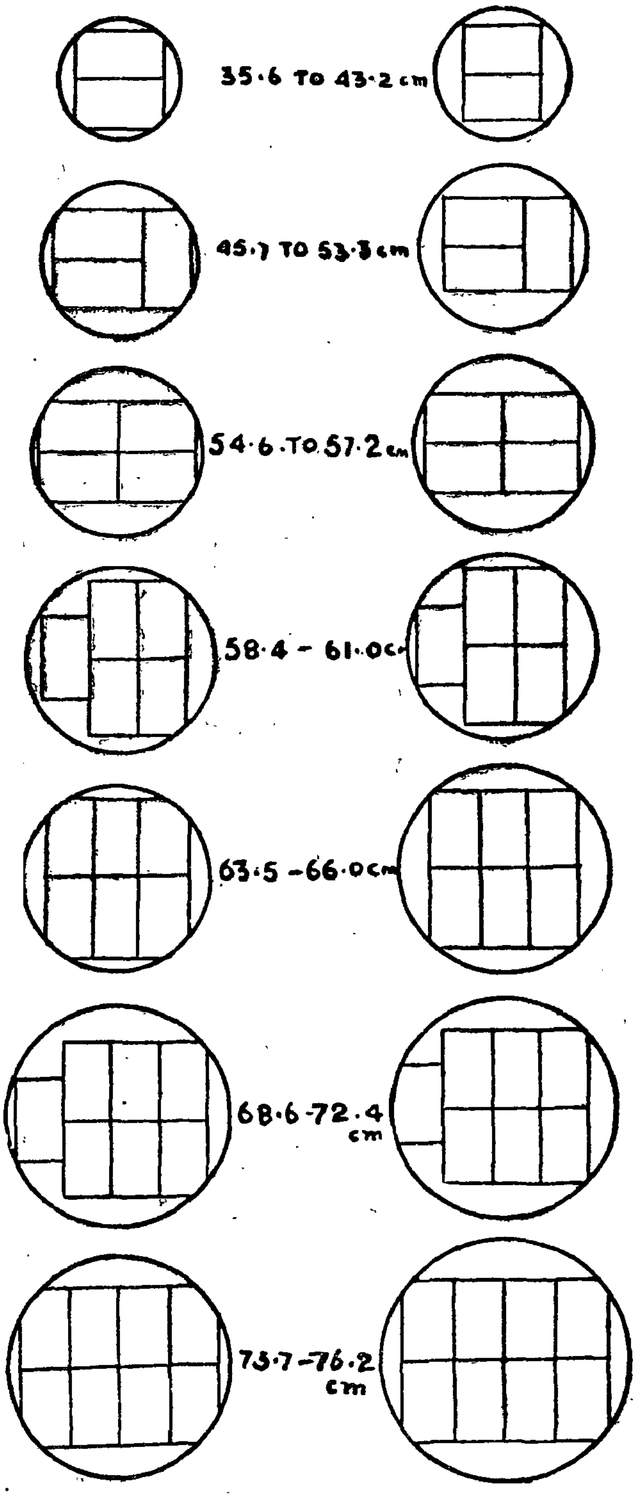


Fig. I—20. Methods of cutting B. G. sleepers.

The cutting of both Broad Gauge and Metre Gauge sleepers from the same tree is sometimes practised, and by this means it is often possible to convert a log far more economically than by cutting Broad Gauge sleepers only. It is useless nowadays to saw anything but really good logs into sleeper sizes, as the conversion of inferior logs only leads to increased rejections and differences of opinion between the producer and the buyer. It is generally better to saw knotty logs into other commercial sizes for which a market exists.

The requirement of the railways in India is near about 5,800,000 sleepers of all kinds a year. Against this there is the ever-increasing popularity of metal sleepers. Quality in the wooden sleepers is therefore an important criterion if such sleepers are to hold their own with metal, and as the sawing of sleepers affects the quality in no small degree, this subject is one which every forest officer will do well to study, so as to get the best possible output, both in quantity and quality, from the forest over which he holds control. At the same time, it is well to remember that it is more beneficial to the Forest Department to supply a large number of sleepers on a reasonably easy specification than to supply a small number on a stiff specification at a higher price.

Machine-sawing

Machine-sawing, under favourable conditions, should usually be a more profitable undertaking than hand-sawing. The essential factors for the successful establishment of machine-sawing are as follows :

(1) There is a sufficient supply of timber to keep the machine continuously at work.

(2) The timber can be sold more profitably after conversion than in the round.

(3) The cost of machine-sawing is less than that of local hand-sawing.

If these essentials exist, there is every prospect of machine-sawing being successful.

The establishment of a sawmill, however, means the sinking of much capital on machinery, etc., and anyone contemplating such an enterprise would be well advised to study local conditions carefully before plunging into such a venture. The communications to and from the mill are specially important features, as without the means of bringing logs cheaply to the saws, and taking converted material away, a sawmill stands a poor chance of being successful. The material to be sawn is also a factor not to be overlooked, as the percentage of waste plays an important part in such a venture. Finally, labour conditions must be studied, and especially the available supply of hand-sawyers, as it would obviously be unwise to start machine-sawing where a plentiful supply of hand-sawyers is available at rates that would make hand-sawing cheaper than machine-sawing. In the majority of forest districts of India, hand-sawing is preferred to machine-sawing, but there are several areas where machine-sawing has proved a profitable undertaking. Of late small semi-portable sawing outfits have been introduced for the conversion of logs in the forest, and where properly supervised by an experienced hand, these have proved successful. A little variation in organisation and supervision makes all the difference between profit and loss in mills of this kind, and so the greatest care should be taken in appraising the local conditions and, above all, in having a practical sawmill-man of experience in charge of the operations.

Speaking in general terms, there are two distinct types of sawmills, namely, those mills that are situated in the forest itself and those that are at some central place away from the forest. The former are usually small mills with perhaps one or two machine-saws and their auxiliaries, while the latter may be very large concerns handling many thousands of tons of logs per annum and equipped with all the different types of machines used for the conversion of logs into planks, scantlings, battens and other forms of sawn material required by the market. Recently, portable sawmills have been introduced in the market. These can be dismantled into sections, each section weighing about two quintals or so, which can be transported by men over mountainous terrain. Portable sawmills can it therefore be installed in interior forests where roads do not exist.

In a number of States, e.g., Bengal, Maharashtra, Mysore and the Andaman Islands, sawmills are worked successfully by the State Forest Departments. There are numerous privately owned

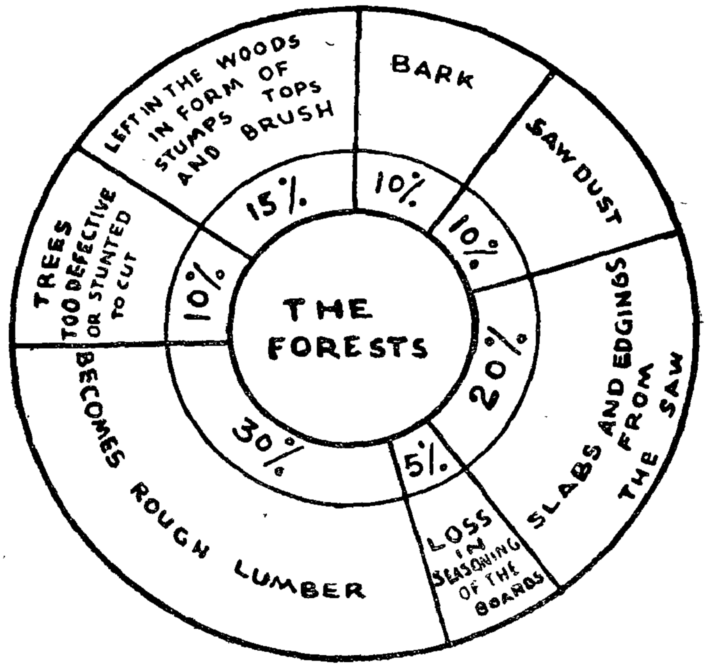


Fig. I—21. Wastage in conversion.

small sawmills practically all over the country. Large sawmills are more common on the West Coast and at the large railway centres in India, where immense quantities of converted material are required by railway-carriage and wagon-shops.

It is not the intension here to discuss the details of machine-sawing and sawmills, as this subject is dealt with in full in Chapter IV. However, it may be mentioned here that machine-sawing is more accurate than hand-sawing and that the conversion percentage is also higher.

Where the forest goes

It has been calculated (in America, but this applies more or less equally to India also) that only about a third of the wood in a well-managed forest becomes finally usuable timber. Fig. I—21 illustrates this.

REFERENCES

1. Anon.	1932	Departmental Exploitation; *Punjab Forest Leaflet* No. 9 : Supdt. Govt. Printing Press, Punjab, Lahore.
2. Asthana, M. N.	1963	Safety Measures in Logging; *Journal of the Society of Indian Foresters*, Vol. III, No. 1, March, 1963.
3. Brown, N. C.	1958	Logging ; John Wiley & Sons, Inc., London.
4. Brown, N. C. & James, S.B.	1958	Lumber; John Wiley & Sons, Inc., London.
5. Fernandez, E. E.	1891	Notes on the Utilization of Forests, Thomson Civil Engineering College Press, Roorkee.
6. Niranjan Singh, Asthana, M. N. & Bhatia, D. N.	1966	Modern Logging Tools, Equipments and Techniques as introduced at the Logging Training Centre, Batote; *Indian Forest Records*, Vol. 1, No. 1 (Logging).
7. Ratra, R. S.	1960	Manual for Wood Cutters No. 1, "Felling of Trees"; National Buildings Organization, New Delhi.
8. Ratra, R. S.	1960	Manual for Wood Cutters No. 2, "Maintenance of Saws"; National Buildings Organization, New Delhi.
9. Troup, R. S.	1913	Indian Forest Utilization; Superintendent, Government Printing, India.
10. Trotter, H.	1940	Manual of Indian Forest Utilization; Humphrey Milford, Oxford University Press.
11. Wackermann, A. E.	1949	Harvesting Timber Crops, McGraw-Hill Book Company, New York.

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CHAPTER II

LOGGING—2. TRANSPORT

General Remarks

Minor and major transportation

Transport of timber from the stump site to its final destination, that is, the market or other consuming centres, may be divided into two parts : minor transportation, generally known as *skidding*, and major transportation. Skidding, also known as *yarding*, consists of short distance movement of timber from the stump site to the points of loading or launching for major transportation, that is, eventual transportation to the final destination. In some cases, as for example, loading of timber direct on the truck at the stump site, skidding may be altogether eliminated.

Forest Roads

Under this heading are included all types of roads, whether permanent or temporary, main roads or small extraction paths. These will come partly under minor transportation and partly under major transportation, and are dealt with separately for the sake of convenience.

Permanent roads are those laid out as part of the general scheme of management. A well-devised road scheme should invariably be projected with due consideration for future extraction requirements. This is particularly important in the plains. In the hills, the ordinary roads and inspection paths are not of much use for timber extraction. The principal roads in a system should be in, or lead to, direct communication with timber markets, rail-heads, or waterways, and every subsidiary road or path should be made to serve as large an area of forest as possible.

Temporary roads intended only for timber extraction are constructed wherever necessary to supplement the permanent roads. In the plains, they may be unnecessary if a good system of permanent roads and rides exists, but temporary roads will be required where logs have to be dragged, as this method of extraction is very damaging to permanent forest roads and should not be employed on them more than is absolutely necessary.

In the hills, log-rolling roads and sleeper-paths cannot often be combined with ordinary roads, and must therefore form part of a special extraction project. They are generally of a temporary nature. Roads and paths used for transport of timber differ according to the means employed to extract the timber and, to some extent, the form of the timber, i.e., whether it is in the form of logs or converted material.

Choice of Method

Before deciding on what method of transport to adopt, or the advisability of changing an existing method, a number of important considerations have to be taken into account, and their relative values balanced each against the others. The more important of these considerations are briefly dealt with below.

Cost

Ordinarily, the cheapest method is the most preferable if it is feasible. If a change of method is contemplated, a careful comparison of the costs of the existing and proposed methods must be made. Capital expenditure, if any, must be considered, the amount of produce available must be estimated, the working, maintenance and direct charges must be found by spreading the cost over the estimated output. Finally, depreciation and, possibly, interest charges must be considered.

Loss and damage to the produce

This is very important. A slight saving in the direct cost of transport by introducing a new method may be offset by increased loss or damage involved in it. Generally, any method which reduces loss or damage is to be recommended.

The time factor

In general, that method which is the most expeditious in delivery of timber at the sale depots is to be preferred. As a rule, any advantage from the seasoning and drying of timber during protracted delivery is more than balanced by a loss from insect damage and decay. In addition, many timbers are more easily sawn when green, and early conversion may be advisable.

Labour

Where labour or the supply of draught animals is scarce, the introduction of labour-saving methods may be beneficial, resulting in greatly increased yields. The introduction of mechanical transport also tends to bring down the local cost of carting and labour, which reacts to the benefit of employees and forest exploitation generally.

Forest improvement

The beneficial effects from the point of view of improving and opening out the forests and making them more accessible must also be considered. For example, the introduction of a good road system might possibly be of greater indirect, if not direct, benefit to a forest estate, than the introduction of a railway system. The introduction of ropeways often opens up possibilities of working forests that were hitherto inaccessible.

Nature of the country

The suitability of the terrain for any proposed method of transport must be carefully considered in all its aspects before deciding on any means of transport. For example, forest railways are no use in very hilly country, and aerial transport is usually unnecessary on level ground.

Size of timber

Some methods are suitable for the extraction of small timber, whereas for heavy logs other methods may be necessary. Factors like heavy undergrowth and windfall may also influence the selection of method.

Silvicultural considerations

Transport of timber through the forest usually involves damage to the soil and the remaining stand, including regeneration, to varying extent. Generally, methods causing the least damage should be preferred.

Climate factors

Land transportation on earth roads is usually not possible during the rainy season. In areas where sufficient snow is available in winter, skidding with the sleds may be advantageous.

Value of the timber

If the timber is of species which fetch comparatively higher prices, costlier methods of transportation can, if necessary, be adopted than would otherwise be justified.

Minor Transportation or Skidding

Various methods used in skidding are described below :

Dragging by means of animals

The draught animals used in India for extraction of timber from the forests are elephants, buffaloes and bullocks, the first two being the strongest. Ordinary forest roads should not be used, but rough earth roads should be prepared by felling trees and removing stumps and other obstructions; with large obstructions the alignment may be made to pass round them. Slopes against the load as also large fluctuations in the low and high gradients should be avoided as far as possible. In soft ground, cordway roads are made by half sinking suitably sized round billets across the road at short intervals. In some cases, dragging may be facilitated by placing round billets in front of the log to act as rollers; these are taken up from behind and again placed in front as the log proceeds. A log can be moved along very rapidly by this means if the gang working the rollers is efficient at its work.

Chains are generally used for dragging, though forest fibre ropes are not infrequently used. They are attached to the log in a variety of ways. Large ringbolts with a very coarse thread are sometimes screwed into holes augered into the log about 30 cm from the end. Another common method is to pass the dragging chain round the end of the log, driving in a short iron bolt just in front of the chain to stop it slipping. The method used most commonly, however, is to cut drag-holes near the end of the log and to pass the chain through it. These drag-holes can again be used subsequently in rafting. However, as already mentioned, cutting drag-holes results in wasting a part of the log at the time of conversion. It is therefore better to fasten the logs with choker ropes (Fig. II-1), as is done in many foreign countries. It is important to see that the attachment is made on that side of the log which will allow the best dragging surface to be in contact with the ground. As mentioned earlier, the front end of the log is slightly rounded off to prevent it from ploughing into the ground, but this rounding of the end must not be excessive, or timber will be wasted. In some districts in India, short wooden sleds are sometimes used to raise the leading end of the log, and this avoids snouting and helps the log to slide well. Where logs have to be dragged up steep slopes, a system of pulley blocks can be used.

Where animals are employed, dragging has to stop during the hot weather, and work should be so organised that extraction is complete before the hot weather begins. Dragging is not really a very efficient method of extraction, but is often the only one possible. It is moreover very destructive to road surfaces and should not be permitted on roads if other forms of transport are possible.

Extraction by means of carts and pairs of wheels

Wherever roads or cart-tracks can be used, carts should be used in preference to dragging. Approximately twice the load that can be moved by dragging with the same animal power can be carried on a cart, and the distance will be covered in a shorter time. For very short distances, however, it may be cheaper to drag than to cart the timber owing to the time taken in loading. The ordinary country cart is quite suitable for carrying small logs. In Burma, timber carts of various types are used. They differ mainly in the sizes of their wheels. In general, they consist merely of a pair of wheels with a strong wooden block, slightly concave at the centre and fixed over the axle, and a pair of shafts. The log is supported on the wooden block over the axle. In Europe and other countries, logs are transported by slinging them in chains below the axles of one or more pairs of large wheels. In the former case, the small end of the log trails on the ground behind. In the latter case, the heavy end of the log rests over the axle of the front pair of wheels, and the small end is suspended under that of the rear pair.

In India, country carts are used extensively for the carriage of timber and firewood. This method of transport is cheap and very suitable for a country like India where carts are familiar to all.

Four-wheeled pneumatic-tyred carts for transportation of timber by animal power are in use in European countries. The front and the hind parts can be disconnected to facilitate transportation. The two parts can be clamped together very easily and the length of the cart can be manipulated to suit the length of the logs required to be transported. Its construction being in two parts, the cart can negotiate sharp bends and can turn over a smaller width. There are mechanical hand brakes on the front as well as on the hind wheels, operated separately by levers. Capable of being driven by a single bullock or a team, these carts carry loads downhill, only empty carts being pulled uphill. A regular gradient, not exceeding 12% and a minium road width of 2.4 m (8 ft.) are necessary. A regular gradient is helpful for adjusting the brakes. These carts can carry a load of up to 3 tons. A few of these carts have now been introduced in the mountain forests of India.

Extraction by rolling

In the plains, rolling roads may be made on flat ground or gentle slopes by clearing away all obstructions along the desired alignment. Logs can be rolled by elephants, by men using stout wooden levers, or preferably by some such log-rolling tools as the cant-hooks or peavies. Rolling roads are extensively used in the Himalayas (Fig. II-2), where they are employed for transporting logs across steep slopes. These roads are generally expensive to construct, and a logging scheme entailing such road construction should not be undertaken without carefully counting the cost beforehand. Hill logging-roads are almost always combined with some other system, such as chutes or slides, in a general scheme of extraction. The roads act as collectors or as the means of linking

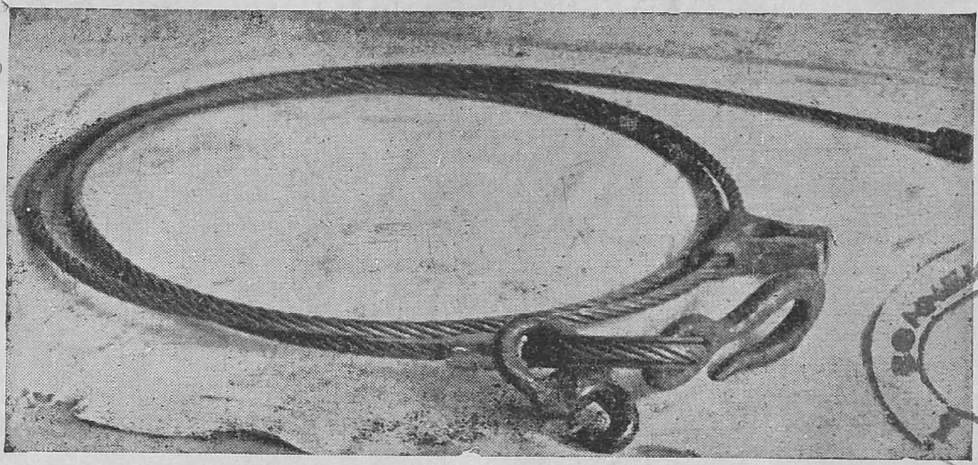

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Fig. II—1. Choker Rope.

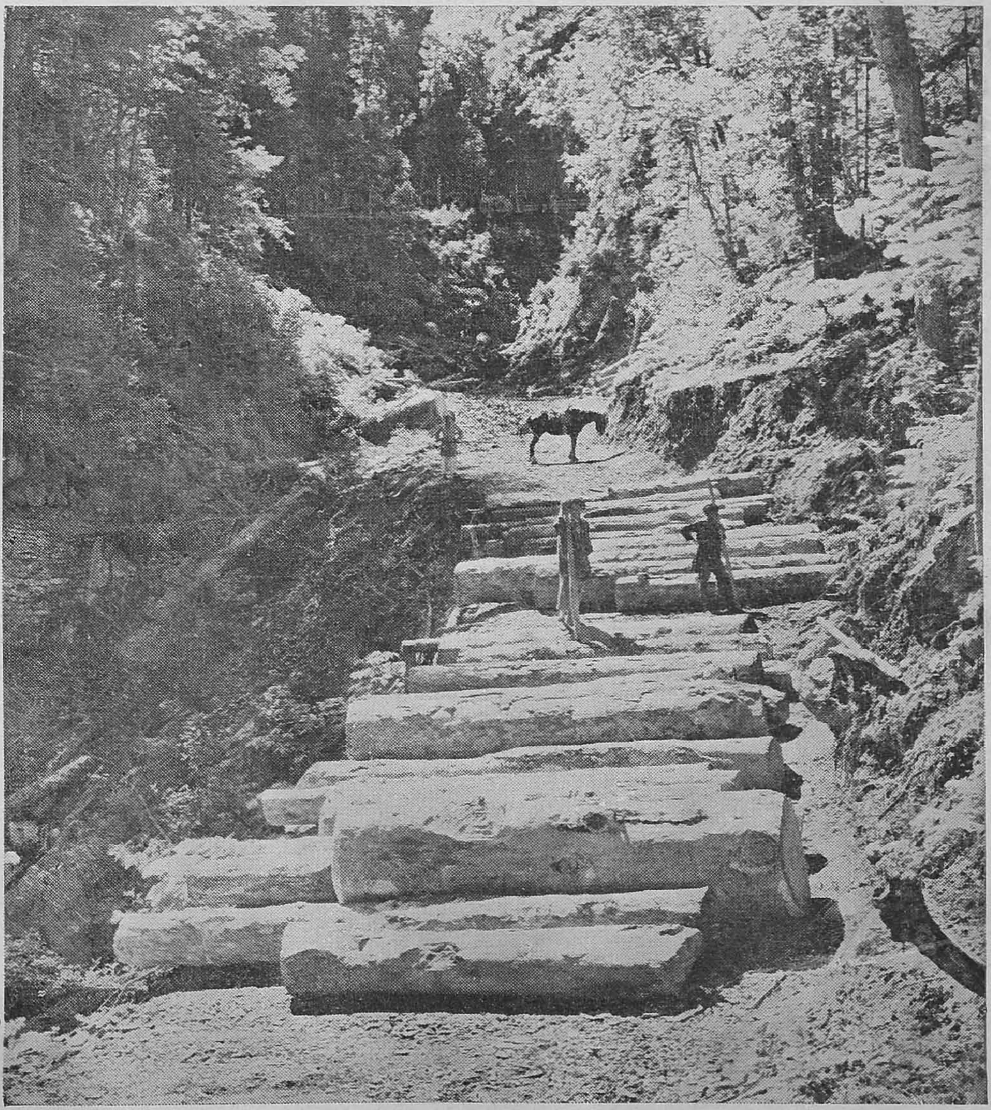

Fig. II—2. Log rolling road.

DONALD GRAVITY AERIAL ROPEWAY

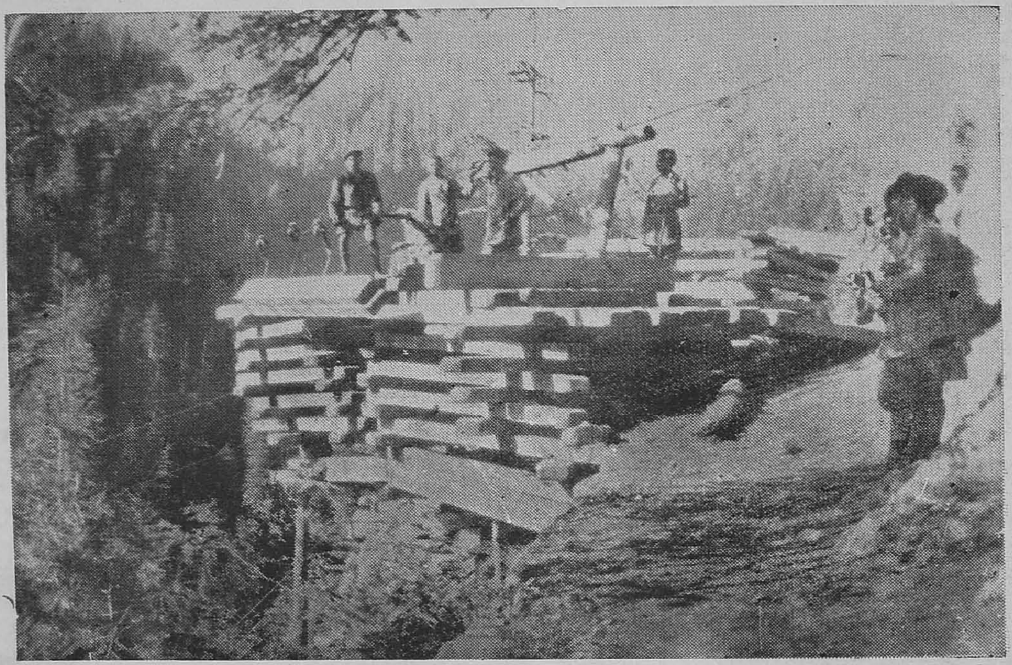

Fig. II—3. Top or the loading station.

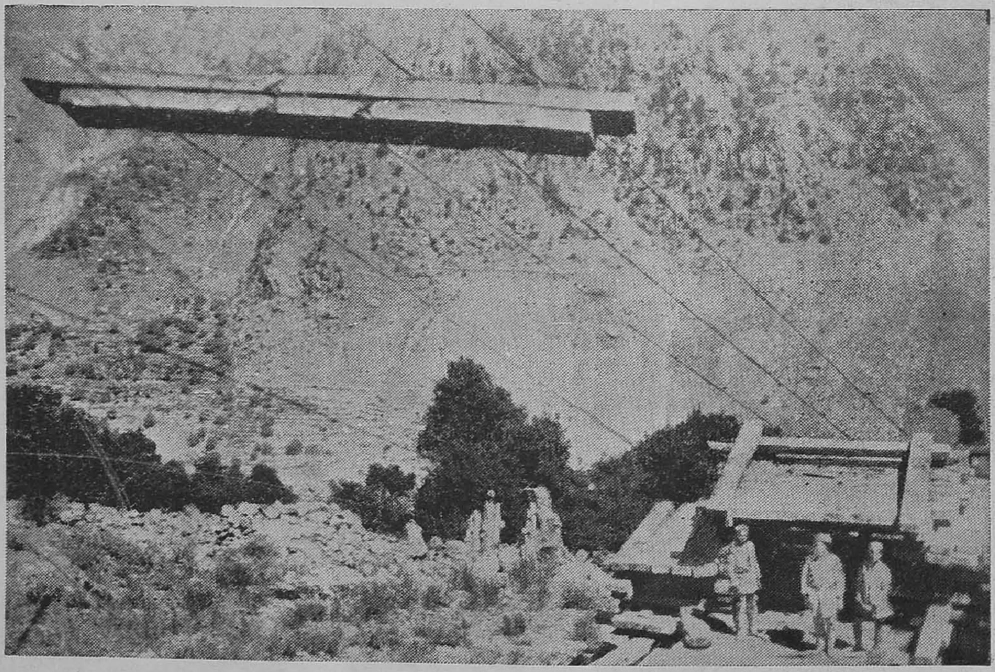

Fig. II—4. Bottom or the unloading station.

up two suitable sites for each chutes. In the alignment of these roads, curves should be avoided as much as possible. The maximum gradient should be 10° and the mean gradient about 3°. Abrupt changes in gradient are undesirable. These roads are constructed in the same way as ordinary roads, and while it is important that the outer edge should be well supported, no money should be wasted on unnecessary finish. The width depends on the length of the largest logs. Rails to facilitate rolling are sometimes made by laying two parallel rows of poles half sunk in the ground, but this is not advisable on steep slopes, as logs are apt to roll too quickly and get out of control. Rolling work is not unattended with danger and must be carefully controlled. Only one log should be moved at a time in each sector. The first log of a batch should be rolled for a short distance only and then wedged secure with stones. The next log should then be rolled up to it, and so on, until the whole batch has been moved. Wooden levers or peavies are the only tools used for rolling logs. Rolling is usually done on contract, at so much per cubic metre on delivery at the launching depot. The construction of roads, chutes, and check-walls are done departmentally.

Carriage by men and pack animals

Pack animals, such as camels, mules and donkeys, afford a cheap method of trasnport where carts cannot be used or are not available. Camels are sometimes used in northern India for the carriage of sleepers. Mules, ponies and donkeys often carry firewood, but their loads are considerably less than those carried in carts.

In the Himalayas, scantlings and sleepers are usually carried from the forest to launching or other depots on men's backs. Rough carriage paths costing only a few rupees per kilometre are constructed for this purpose. These paths are often only 30—45 cm wide, except where they have to cross precipitous ground, when they have to be carefully constructed and may be rather costly. Carriage by men is usually done on contract, the rates paid for delivery at the launching depot depending on the size of the timber and the length of the carriage path. This method is replaced wherever possible by overhead transport, as the labourers demand high wages and their availability is often uncertain.

Skyline or overhead cable-skidding systems

Overhead cable-skidding] means the extraction of forest produce by means of aerial ropeways. Ropeways can be divided into two main classes :

(1) Gravity ropeways.

(2) Power ropeways.

In gravity ropeways the motive power is supplied by the weight of the material which is transported down the cables. This type of ropeway can therefore be used only where the nature of the ground is such that the cables can be so fixed that a sufficient slope is given to allow the load to descend by itself to the bottom. With power ropeways, the load is moved by means of an engine, so that they can be operated over flat ground or even to move loads uphill.

(1) *Gravity ropeways.*—Gravity ropeways are extensively used in Europe, and of late their use has increased in India, but they are not likely to be very widely used, partly because the system of sale of coupes to contractors is widespread, and these men, even if they had the means of purchasing ropeways, could never be certain of continuous employment in the same locality. In addition, the extraction of logs by gravity ropeways in the Himalayas is scarcely practicable, as it is not possible to handle the heavy cables which would be necessary to transport large logs. Again, the systems of management usually in force in the hills would necessitate the frequent shifting of the ropeway from one locality to another. These conditions generally preclude the employment of heavy tackle. It is natural, therefore, that extension in the use of gravity ropeways has been almost entirely in the direction of lightness and portability, and has culminated in the perfection of a light and portable system suitable for sleeper and scantling extraction. This system is described later on.

In its most elementary form, a gravity ropeway consists of a wire cable stretched between two points, at both of which it is anchored. The inclination of the cable should be sufficient to allow the load to slide down with sufficient force to reach the bottom. The load is usually attached to and runs the cable, either by means of a wooden saddle or a pulley-wheel, the correct amount of sag being

given to the rope to allow the load to arrive at the bottom station without undue speed. Preferably the load should stop of itself as it reaches the lower station. If the method of attachment is by pulley-wheel, the system cannot be used on very steep gradients, as there is very little braking effect from friction and the timber would increase in speed rather than lose it. There is always the danger of the load striking the lower station and causing damage, and this system is therefore suitable only for the extraction of light material such as firewood.

The more common practice is to use a moving control rope in conjunction with one or more fixed ropes. The loads are attached to the control rope, and their speed of descent can thereby be regulated. This system can therefore be used on much steeper gradients than the elementary form earlier mentioned. There are variations in the use of the control rope in ropeways. In some the control rope is endless, passing round sheaves or drums at the upper and lower stations. In another type there are two control ropes and two fixed ropes, the two control ropes being fixed to a drum at the top station in such a way that one unwinds letting down the descending load while the other winds up drawing up the empty carriers. Another variation is a single fixed rope system with a single open control rope which passes round a drum at the top station. One end of the rope is attached to the load at the top while the other is at the bottom; as the load descends it draws up the other end of the control rope which is attached to the empty carriers. At the point where the two meet half-way there i a special device fixed on a standard whereby the two can pass one another.

The system which has proved most useful for sleeper and scantling extraction in the north-western Himalayas is known as the 'Donald Portable Gravity Ropeway' (Fig. II-3, 4 & 5). This system consists of three fixed track rope of 2.5 cm circumference set parallel to one another at about one metre intervals. They are anchored at the top and bottom stations, and are stretched to the required tension by rough windlasses at the bottom station (Fig. II-5). The endless control rope, which is rather lighter (1.9 cm circumference) and more flexible than the fixed ropes, runs round two cast-iron grooved sheaves, the two ends being joined by a long splice. The load is suspended crosswise below the three fixed ropes by three carriers, which consist of pulleys and an attachment to which wire slings fastened round the load can be hooked. Another wire sling round the centre of the load is fastened to an 'eye' let into the control rope. When the load descends it pulls up the empty carriers which hang from another 'eye' at the lower end of the control rope. As soon as a load reaches the bottom station the scantlings are removed, and the empty carriers are attached to the control rope, during which time another load is prepared at the top station. A simple but effective lever-operated band-brake is operated on the sheave at the bottom station. The great advantage of this system is its portability and simplicity. It has not been found difficult to train local labour in its use; no special engineering skill is required, and the spans can easily be erected, operated and dismantled by the local staff. The Donald ropeway is worthy of wider use. The following features are useful to know :

(1) The ropes can be coiled up into linked bundles and easily carried by a string of labourers.

(2) The sheaves are easily portable.

(3) Since a brake is used, the ropeway can be operated at quite steep inclinations, 45° being the steepest yet used; 17° is about the lowest practicable inclination. The best lengths and grades for speed and economy are, respectively, 750 to 1,050 metres and 22° to 35° between station.

(4) Spans above 1,200 metres are difficult to erect and operate. Quite short spans of only two to three hundred metres are often used to carry timber across ravines, and the use of these ropeways has made possible the working of many forests, which had previously been looked upon as inaccessible from the extraction point of view. An extraction scheme often involves the linking up on a number of suitable station sites by several spans in series.

(5) The safe working load is 0.25 cubic metres or about 225 kg of green timber, though the life of the ropes would be prolonged if lighter loads were carried.

(6) Roping is usually done on contract, a flat rate being paid for each scantling. The rates vary from Re. 0.08 to Re. 0.12 per scantling per span, according to length of the span. The costs for erecting and dismantling spans depend upon the length of the span and the terrain, and vary greatly. Erection costs vary from about Rs. 70 to Rs. 160 and the costs of dismantling from about Rs. 25 to Rs. 50.

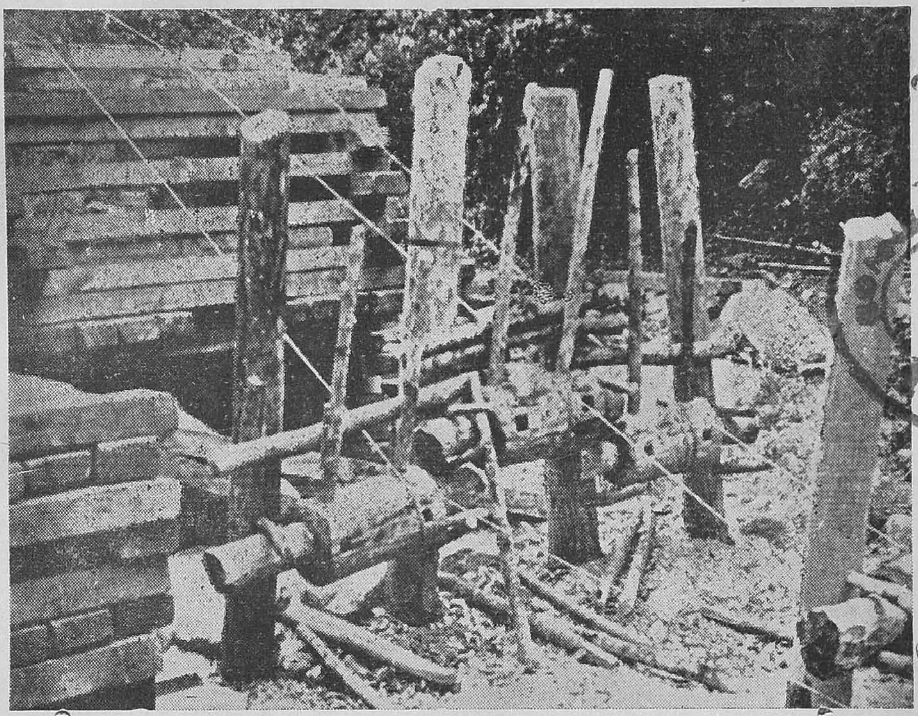

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Fig. II—5. Bottom station of the Donald Gravity Ropeways showing anchorage and the winches for tensioning the cable.

Fig. II—6. Dry wooden slide for sawn timber in Himachal Pradesh.

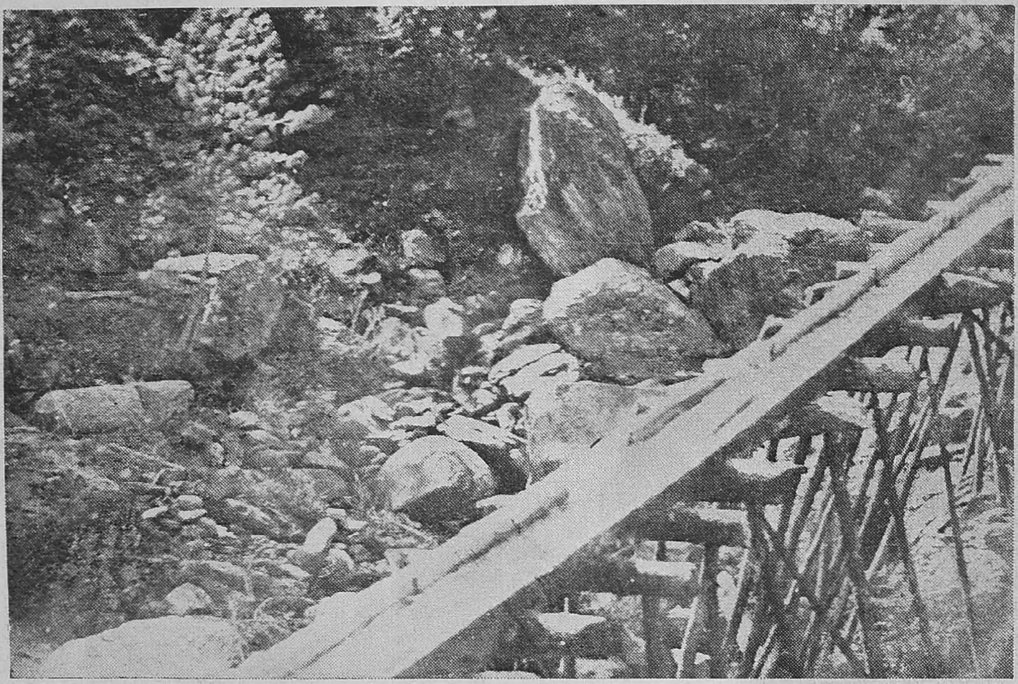

Fig. II—7. Wet slide.

Fig. II—8. Cross-haul method of loading. Log fitted with cable halfway up the sleepers. The two unskilled workers help the proper balancing of the log but do not have to push it.

The life of wire ropes depends entirely on how they are handled and how often they are moved from one site to another. The life can be greatly increased by observing the following precautions :

(1) When coiling and uncoiling the ropes and when setting up or dismantling the spans, care must be taken to avoid kinks. Some kinks are bound to occur, but they should be carefully taken out before the ropes are used again. A rope quickly frays at places where it loses its round shape.

(2) Care must be taken to see that the two sheaves are in exact alignment, so that the rope will run in the centre of the groove. Wear and tear are greatly increased if this is not done.

(3) The three fixed ropes should have, as nearly as possible, the same tension.

(4) The two ends of the control rope must be very carefully spliced together.

(5) Scantlings should be so loaded that the weight is equally distributed under the three fixed ropes; this ensures equal wear on all three.

(6) All ropes must be kept well oiled.

(7) The maximum load permissible must never be exceeded.

(8) Loads should not be allowed to descend too rapidly. Apart from possible danger, a fierce application of the brake often causes the control rope to skid round the sheave and increases the wear.

(9) If ropes are kept well oiled it is better to leave them up over the winter, as the more the ropes are handled the quicker they deteriorate.

(10) It is essential to keep a careful record of all ropes. This record should give the date when a rope was first put into use, the number of times it has been moved, and details of the scantlings carried.

Another method based on the same principle is the so-called 'Koroleff's wire skidding' method developed in Canada. This method has been successfully tried in Uttar Pradesh and Bihar. The equipment consists of a steel wire 8 S.W.G., stretched between two trees, one at the top and the other at the bottom, and anchored to them. Loads up to a maximum of 300 kg are carried down by gravity by means of expendable wooden carriers suspended to the main wire by means of wire slings. The load, on reaching the bottom station, strikes an old truck tyre and thereby gets discharged. Spans up to 450 metres have been worked with over down grades from 20% to 65%. This method is suitable for transporting pulpwood and firewood, but has also been tried and found suitable for transporting *sabai* grass.

In conclusion, it can be said that gravity ropeways are the most efficient means of transporting timber in hilly country. They deliver timber in the least damaged condition, are very cheap and adaptable and are speedy in delivering timber at the depots.

(2) *Power ropeways.*—Power ropeways are not being commonly used in forest extraction work in India. They belong to one of the various cable-hauling systems in which the power machine operating in a stationary position pulls in timber from a distance by means of a wire-rope cable wound on a drum. In contrast, the direct tractive machine, such as the tractor, moves while skidding and drags the logs along with it. Power ropeways employed for overhead skidding consist of a fixed cable attached to trees or spars, along which a special carrier conveying the timber runs. The hauling cable is attached to the carrier which moves along the fixed cable as the drum winds in the hauling cable. Such ropeways are commonly known as the *Skyline cranes*. They have recently been brought into use in Jammu and Kashmir, Uttar Pradesh and the Andaman Islands. Skyline cranes can transport timber uphill, downhill, and on level ground; in downhill transport the brakes of the power machine control the speed of the carrier through the hauling cable. Modern skyline cranes are capable of carrying loads up to 10 tons over spans of 2,000 metres and gradient from 15 to 80%. Skyline cranes are costly and their use will be justified only when a sufficiently large quantity of timber is to be transported in log form over a comparatively difficult terrain.

Other cable-hauling systems comprise *ground-lead skidding* and *high-lead skidding*. In ground-lead skidding, logs are pulled on the ground by a power unit with single drum on which the cable is wound to draw in the logs fastened to the other end. Pulling back the cable for a fresh haul is done by hand, animal or tractor power. This is a slow and tedious process and is avoided by using two drums with a power unit insted of one, the second for rehauling the main cable back into the woods.

through a system of blocks attached to the stumps. In high-lead skidding, a similar two-drum power unit is used, but the skidding line is elevated at the pulling end by hanging the main-line lead block high on a spar or tree to give the nose of the log a lift to overcome obstructions. None of these systems is employed in India, but these are commonly used elsewhere, specially in U.S.A. and Canada. Both these systems do considerable damage to the ground and to regeneration.

A Fordson tractor fitted with Tom Huston winch is being used in Nagzeri valley of Mysore State for ground skidding of logs along moderately steep slopes. The main skidding cable is a 16 mm diameter galvanised steel wire rope with a breaking load of 13.7 tons. Skidding of logs is done along a drag path specially prepared by clearing the ground. The log is kept under control with the help of peavies, ballies, etc., by the men accompanying it, who also free it from obstructions like projecting stones, stumps, etc. The same men drag down the rope on the return journey and fasten it to the next log.

Skidding by tractors

The latest trend is to use wheeled tractors with rubber tyres for skidding except in marshy or swampy tracts where crawler-type tractors are employed. Temporary roads have to be built for the movement of tractors, but where topography is comparatively level and the forest not too dense, few roads, if any, are needed, the tractor beating down saplings and bushes and itself making a road. When skidding roads have to be built, the skidding tractors are also equipped with bulldozers for road construction. The usefulness of a tractor in skidding is greatly increased when it is equipped with a winch connected to the power take-off of the tractor. With the winch the logs can be pulled from where they lie to the rear of the stationary tractor, thereby facilitating skidding operations. Certain devices are used to facilitate haulage of logs by tractors over short distances. One such device is the skidding pan in which the front ends of the logs rest over a pan made of sheet-metal plate curved upward at the front so as to prevent the logs from gouging in to the ground. Another device is the skidding arch which consists of a frame resting on two wheels, the cable of the tractor's winch passing through a block at its top. This has the advantage of supporting the load, and consequently avoids skidding the greater part of the log on the ground.

Proper maintenance is of great importance for the economic working of tractors. Tractors are extensively used for skidding in many countries, but have not been used so far in India to any appreciable extent.

Skidding of timber on sleds over snow

In western countries the greatest possible advantage is taken of snow, either to skid logs at uncontrolled speeds on skidways, or to extract them at controlled speed on sleds with horse or man p[illegible] and utilising gravity whenever possible. For sledding, a minimum depth of 0.5 metre of snow lasting for 2 to 3 months should be available. Sled roads, about 2 metres wide and with a gradient of about 15%, have to be constructed. Skidding over snow by sleds has not so far been done in India, but regions above about 2,250 metres in the Himalayas appear to be suitable for this sort of work, which does not involve any large capital outlay.

Timber Slides

Timber slides generally constitute an intermediate step between skidding and some form of major transportation. However, for the sake of convenience they may be considered here. Various types of timber slides used in India are described below.

Earth slides

Log slides are sometimes used in the Himalayas, but they require a very large outturn to justify or even make possible their construction. The more common form of logs slide used is the earth slide or earth chute which merely consists of a trough scooped out down the hillside. Small stream-beds, provided they are not too steep or rocky, can serve the same purpose, and are frequently used as sections of rolling roads. Log sliding in earth chutes has to be done carefully, or logs may be badly damaged by smashing against rocks, or heaps of logs may be damaged by others crashing into them from above. Logs must be kept under control when sliding or rolling is done, and where the gradient makes this impossible

It is necessary to construct stout check-walls at intervals down the slide or chute. These check-wall can be made by firmly sinking a row of logs vertically in the ground to form a palisade. The upper side of the wall is usually banked up with earth and branchwood to save the descending logs from being damaged. Check-walls are also constructed where a change of direction is necessary. When the slope is not quite sufficient to provide free movement for sliding down the logs, small poles are usually buried in the ground along the whole length of the chute and the logs are then dragged manually.

Dry wooden slides

Dry wooden slides are trough shaped slides made of logs or poles or sawn timber roughly fitted together, in contradistinction to wet slides which are made of planks or scantlings accurately fitted together so as to hold water.

Dry wooden log slides were at one time used in the Himalayas, but with the decline in demand for long wooden beams their use is now rare. They require a very large outturn to justify their construction. This form of slide is usually employed when the route lies across hill slopes, or in localities where either the ground is very rocky and difficult to clear for an earth slide or it crosses over, or is situated at the edge of cultivated fields. It is made sections of 5 or 6 logs or tree topes (A, A, b, b, c, in Fig. II-9) so disposed as to form a roughly made trough. The two larger pieces (A, A) lying at the outer sides are about 2.3 metres in girth, the inner logs or poles being proportionately smaller. The ends of these logs rest on a roughly made round sleeper (S) to which they are pinned down by a spike of hard wood (K,K). The tendency of the logs to slip forward when the slide is in use is further checked by their

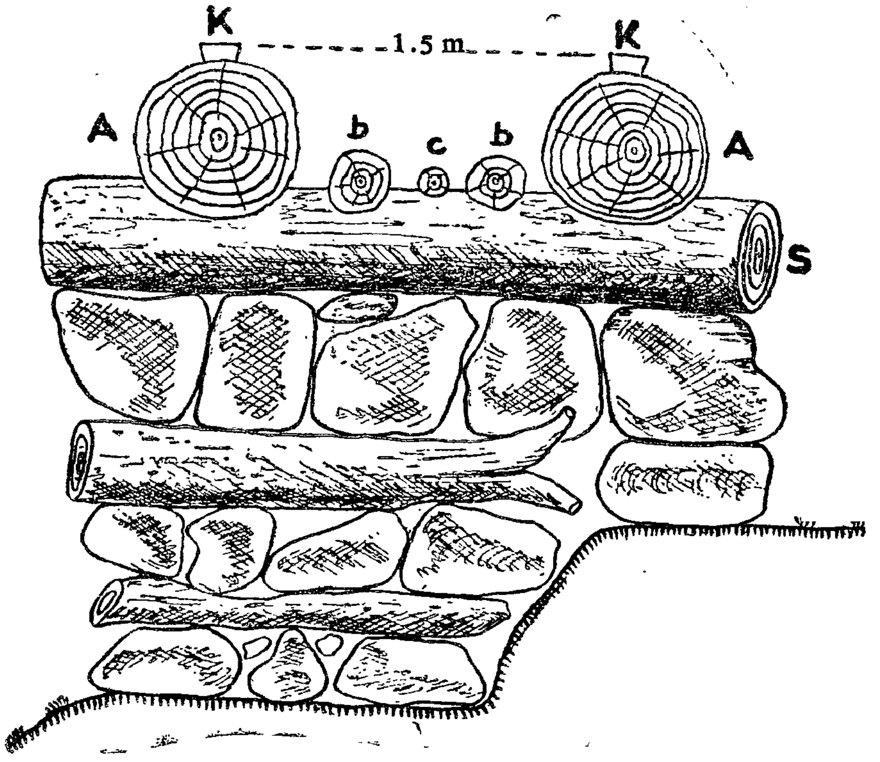

Fig. II—9. Construction of dry wooden slide.

being hollowed out below, so that they hook themselves on to the sleeper. Fig. II-10 shows this and also the method of using the spike. A sufficient gradient must be given so that the logs travel easily; this will be obtained with gradients of 15° to 25°, but if the fall is much over 30° precautions must be taken to avoid accidents, either by throwing earth or sand or cutting notches in the logs forming the base of the slide itself to reduce velocity.

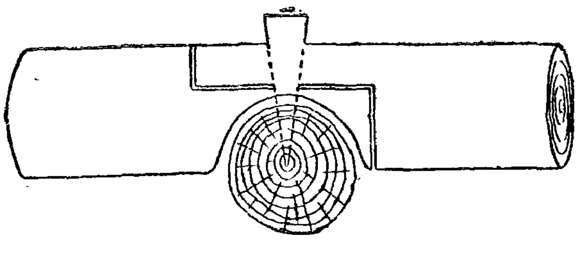

Fig. II—10. Method of using the spike in the dry wooden slide.

Dry slides for extraction of sleepers and scantlings are of more elaborate construction (Fig. II-6). The sawn timber is roughly built up with a saucer shaped framework, each length overlapping the one below. The slide is supported one the outerside by cribwork whenever it crosses a depression. The surface of the slide is kept wet by sprinkling water from the nearest source to reduce friction and facilitate sliding.

Dry slides have many disad vantages and are not much used in India except in short lengths, such as for dicharging scantlings into a river from a depot on a steep bank above it. They are sometimes used for the extraction of firewood also. The chief disadvantages of dry slides are :

(1) The timber suffers considerably more wear and tear than in wet slides.

(2) As the timber travels by its own weight there is little latitude for varying the gradient, and the timber is liable to travel too fast or to stop altogether.

(3) A gradient suitable for dry weather allows the timber to travel too fast when the slide is wet with rain.

(4) It is difficult to run a slide divided into sections, because the timber has to be stopped in hollows dug in the earth at the foot of each section and must be cleared down the succeeding section before another scantling arrives. This is easily accomplished in pools in wet sliding.

(5) No reliance can be placed on brakes or on grit thrown into the slide to check the speed of sliding timber. On steep gradients momentum varies considerably with the same class of timber.

The only advantage of dry slides is that they do not require water-tight joints and can be used where no water is available. Their use is, however, not recommended except where only a short steep length is required and conditions are favourable for their use.

Wet slides or flumes

Wet slides, as a means of extracting railway sleepers and other sawn meterial, have been in use in the north-western Himalayas for a long time, and although they have to some extent been supplanted by portable wire-ropeways, they are still used as one of the chief methods of extraction in some forests In these slides, water is used as a motive power in addition to gravity. Though the subject is essentially a part of forest engineering, a brief description of a wet slide is desirable here so that the management and organisation of side work to be described later can be readily understood.

Briefly, wet slide (Fig. II-7) consists of a rectangular through constructed from convenient classes of timber, mostly sleeper sizes, cut for export in the forest. The pieces used in the slide are exported, when the slide is no longer required. All joints must be made as water-tight as possible. This is effected partly by trimming the wood and partly by stuffing all cracks with moss or grass when the slide is completed.

The trough thus consists of a number of sections, each of the length of the timbers used, which are firmly fixed at each joint into blocks or 'cradles' specially notched to receive them. An additional cradle should be fitted at the centre of each section if increased stability is required. The success of this method of extraction depends on the maintenance of a sufficient and continuous flow of water down the slide. The greater the depth of water the better, for on very low gradients deeper water increases the speed of the scantlings while on the steeper slopes it acts as a very efficient brake as the timber tends to travel faster than the water. It is quite impossible to avoid leakage altogether and as the length of the slide increases the flow of water diminishes. There is, therefore, a limit to the length of slide that can be run continuously without augmenting the water supply. The water supply can, however, be replenished by short lengths of through which carry water to the slide from the original supply or from some side stream. The best method, however, is to divide the slide, if it is a long one, into a number of control sections. Depending on the gradient and water supply, the length of these will naturally vary considerably, but it is best that they should not be much over 200 meteres in length for a 10% gradient with adequate water supply. Each control section receives a fresh supply of water, but in addition to this other advantages accure : (1) control of sliding operations is greately facilate if the slide consists of a number of sections instead of one continuous length; and (2) should one section

break down, the others can still be worked to some extent. Under these circumstances, the whole layout consists of a head pool at the launching depot formed by damming the stream. The timber is launched into the pool and directed down to the first section. At the end of this section another pool is made into which the scantlings are discharged. This pool acts as the head pool for the supply of water for the second section and for directing the scantlings down the second section. This procedure is followed for all other sections, the last section finally discharging the scantlings into the floating stream.

Wet slides are expensive and very vulnerable to damage from floods, landslips, etc., and breakdowns have always to be anticipated. The construction of wet slides frequently demands considerable engineering skill, and no costly scheme should be embarked on before examining all the alternatives. Where the alignment has to follow a difficult valley, information as to the fluctuations and tendencies of the available water supply must be obtained. A well thought out programme, which takes into consideration the time taken to build the slide, the completion of sawing and delivery of the timber at the head of the slide, the earliest date on which it is safe or possible to start sliding operations, and the latest date by which all timber must be delivered at the main floating stream is of the utmost importance. Failure to take all these matters into consideration may result in disaster to the whole scheme, however skilfully the slide may have been constructed.

Wet slide management can only be perfected by experience, but this is often obtained at a high cost, and even though some of the following points may seem trivial at first sight, it will be found in practice that careful attention to them will contribute considerably to the success of any wet slide scheme.

Alignment.—(1) It is generally not possible to operate slides during the rains owing to fluctuation in the level of streams and to the difficulty of dam construction at that time.

(2) It is always necessary to align the slide well above high flood level.

(3) Wet slides can work satisfactorily at as low a gradient as ½° provided that the construction exactly follows the alignment, that the joints are made as water-tight as possible and that a good head of water is maintained.

(4) Unstable ground should be avoided at all cost.

(5) Sharp curves should be advoided, particularly on steep gradients.

(6) Before detailed alignment is undertaken a careful survey must be made of the country to be covered, and all obligatory points and suitable sites for pools carefully examined.

Construction.—(1) Construction should not be started until the alignment has been finally settled.

(2) As much material as possible should be collected at convenient places on the alignment before construction begins.

(3) Work on the more difficult portions of the alignment should not be left to the last; labour gangs should be carefully organized for the various jobs so that there will never be any delay and work will be properly proportioned.

(4) It pays to employ the most experienced slide *mistris* even though at high wages.

(5) The floor of the slide should be of uniform width throughout and not widened at curves as is often advised; jams are far more likely to occur at points where increased width allows two scantlings of different sizes to draw abreast. To allow for the passage of long scantlings round curves, the radius of the curve must be increased. The narrower the trough the better. Usually it should be not more than 15 cm wider than the widest piece of timber to be floated down.

(6) On steep gradients and at sharp curves, the slide must be strengthened by the use of dog-spikes and by increasing the number of cradles.

(7) If the timber being extracted includes more than one species, scantlings of the least valuable species should be used for temporary slide construction, but if the slide is to operate for several years, the most durable species should be used.

(8) Under average conditions a slide *mistri* assisted by an adequate gang of, say, ten labourers, can construct about 1,500 metres of slide in a month.

Slide working.—(1) The slide should be gone over for repairs every morning before work starts. It is also a good plan to stop work for half an hour at midday for an overhaul. A defect seen and corrected in time may save considerable delay later.

(2) It does not pay to launch scantlings down a slide in quick succession, as jams will result. About four scantlings per minute gives the smoothest working and pays in the end.

(3) If possible, timber should be floated down in batches of the same size-class and species. Heavy scantlings travel faster than light ones, and where odd sizes and lengths are sent down, jams are far more likely to occur. Smooth working can only be obtained when scantlings do not overtake one another. Steady continuous working is what should be aimed at.

(4) Adequate arrangements must be made to ensure that there is as little delay as possible in the event of a breakdown.

Cost.—Excluding the cost of sawing and carriage, the cost of constructing a wet slide should rarely exceed Rs. 2.00 per running metre. Construction on inclined rock is thrice, and on high trestling twice, as expensive as on flat ground or on low trestling. Construction, and sometimes maintenance, is expensive, and the use of long wet slides can only be justified by a large outturn. The method does not deliver the timber in as good a condition as either carriage by men or ropeways does, while the timber used in the slide itself depreciates in value. It is a cheaper method of transport than manual carriage, but more expensive than ropeways or 'telescopic' floating, though the last-named method is liable to cause more damage to scantlings. Wet slides are used, other things being favourable, when the topography is unsuitable for ropeways, when the condition of the stream is too unfavourable to permit 'telescopic' floating, and when the length of the lead rules out manual carriage on account of the high cost and delay involved. Once the slide has been constructed, the delivery of the scantlings at the main floating steam is quicker than by any other method.

LOADING

Hand-loading

In India, loading of timber and firewood is usually done by hand. Firewood billets and small size timber is generally loaded manually direct into the carts or other vehicles. Logs can be loaded on carts in various ways. In north-west India, the cart is laid on one side either with or without taking the wheels off; the log is roped to the cart, which is then levered to the upright position with the log attached. In

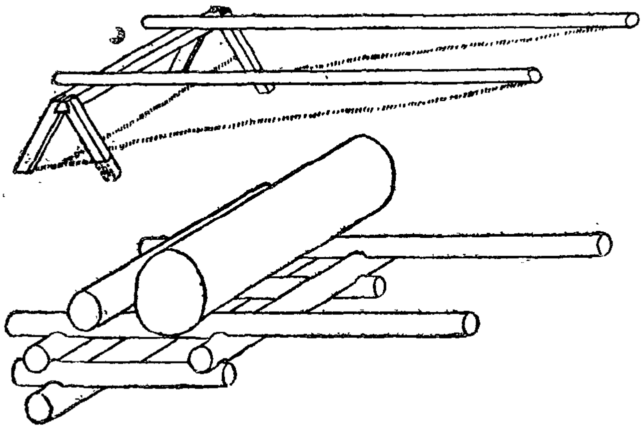

Fig. II—11. Loading docks for logs.

Burma, logs are often rested on a large cross-log and the carts are backed under them. The logs are then levered forward until their balance is transferred from the cross-log to the axle of the cart. The logs are only fastened to the cart by one chain, balance being maintained by the driver who sits on the log. Where large numbers of logs have to be loaded continuously, as at a timber depot, loading is usually done by means of a rough wooden gantry and a block and tackle.

When vehicles are loaded on sloping ground or under a road cut, logs and other round timber can be loaded by rolling them into the vehicle with peavies or cant-hooks from suitable loading dock. Elevated ramps or skidways are constructed for this purpose as shown in Eig. II—8.

Cross haul

In this method (Fig. II—8), the log is simply rolled up a pair of temporarily placed poles or scantlings from the ground to the bed of the truck or wagon. A cable is attached to a stump or tree and, after being passed over the platform of the truck or wagon, is passed round the log in the middle and then attached to a tractor, a team of animals or a winch. When the cable is pulled by the latter, the log will roll up the poles or scantlings to the platform of the truck or wagon.

Power loading

A stationary overhead block for loading is obtained by the use of a gin pole, an A-frame, or a cable attached to a tree or an erected pole. A gin pole is an erect pole, 9 to 12 metres high, guyed on three sides and leaning far enough in one direction so that the block attached at the top is directly over the vehicle to be loaded. A wooden frame, shaped like the letter 'A' and called an A-frame, is used similarly. By attaching the block to one end of a 2 to 3 metre cable and fastening the other end about 6 metres up a tree, a stationary overhead block is obtained. When the loading cable running through the block is pulled, the weight of the log pulls the cable far enough away from the tree to permit parking vehicle beneath it for loading. In all these devices, power for raising the logs may be obtained by a team of animals, by the pull of a tractor or truck, or by a power winch.

Mechanical log loaders and cranes

Various types of mechanical log loaders are being used in the western countries. These are usually fixed on trucks or tractors and worked either hydraulically or electrically. Such log loaders are not in use in India. However, cranes are being used for the loading of logs into railway wagons at most of the places.

Full-Tree Logging

The extraction of entire tree lengths along with branches and leaves from the forests is now widely practised in the U. S. S. R., Canada and Sweden. The trees on being felled are skidded with the crowns from the cutting site by tractors, winches and cable ways to the loading points for loading into trucks with trailers or Narrow Gauge railway wagons. The trees are then taken to a place, called the lower yard, where limbing, crosscutting and further processing is done by fully mechanized means, the trees and the logs being moved from machine to machine by means of conveyor belts. This technique enables much greater utilization of wood, bark and leaves, eliminates the accumulation of slash in the forest, reduces the working costs owing to the possibilities of full mechanization and makes for higher labour output by providing better working conditions.

Full-tree logging has no where been tried in India.

Major Transportation by Land

Forest railways and tramways

The use of light railways and tramways in the forests for timber extraction and transport is very common both in Europe and America and has been developed to a certain extent in India. The initial cost of a railway with its rolling stock is very high and this cost must be distributed over a large quantity of timber to make it economical. Since the selection system with its scattered fellings is still practised extensively in India, there is at present no likelihood of railways or tramways coming to the fore in any great degree. Further, where a good system of waterways exists, water transport will probably always be preferred in spite of its disadvantages, such as higher transit losses and delay in the delivery of timber. In many forest localities the cost of railway construction is prohibitive, on account of the numerous bridges and deep cuttings required. Truck transport has been greatly developed in the post-War years and, being much more economical and simpler, is likely to replace the existing forest railways. In Utter Pradesh, one forest railway out of two had to be closed down recently, after having been in existence for about 20 years, owing to adverse competition with the more economical truck transport.

Forest railways differ from tramways in that the motive power is supplied by an engine, either steam or internal combustion, while on tramways the trucks are either drawn by men or animals, usually the

latter, or are propelled by their own momentum. Another difference lies in the nature of the rails. In railways, the lines are heavy and are laid on wooden sleepers in much the same way as for the ordinary railway. Forest tramways, on the other hand, have light rails which are permanently united with narrow metal sleepers, and are more portable.

Tramways can be used in far more hilly country than railways, as they do not require such an expensive track, but are only used to a limited extent in India. They have the drawback that their carrying capacity is low compared with the cost of purchase and construction. Forest tramways have been used in Burma, Madras, Assam and Uttar Pradesh with success and if, conditions are favourable and sufficient material for extraction is available, they are a good form of transport.

Forest railways are in more common use. In Uttar Pradesh there were two systems working, of which one has been closed down as stated earlier. In Kerala State there was, till recently, a forest railway for the transport of the timber from interior forests to Chalakudi. Forest railways have also been in use for the extraction of firewood from Changa Manga plantations (now in West Pakistan) and for the extraction of unfloatable hardwoods in Burma. The gauge is usually 0·61 metre (2 ft). Metre Gauge railways can also be used, and they are more economical than the 2 ft gauge, as their carrying capacity is far greater while maintenance charges are not much higher. The initial cost of a Metre Gauge line is slightly higher, and it is best used where a large amount of timber can be reached without having to move the rails. Temporary or 'spur' tracks are often laid in conjunction with a permanent export track, in order to connect the latter with the felling areas which change from year to year.

Two conditions must be satisfied before a forest railway or tramway can be profitably laid :

(1) There must be a constant and sufficient demand for the produce.

(2) There must be a sufficiently large quantity of produce available for export near the line of the tramway or its branches.

As an example, where the whole of the produce of a compact block of forest can be exported along one line to reach the market, it may pay to construct a railway. Again, where a plantation is being worked perpetually for fuel, a railway along the common line of export with temporary branches to the annual coupes might prove to be the most economical method of extraction.

Motor trucks

Transport of timber by motor trucks was practically unknown in India before the Second World War. A beginning was made during the war when, due to the emergent demand for timber for war purposes, motor trucks supplied by the Government were employed by contractors to transport timber expeditiously. It was after the war, when rejected army trucks were available in large numbers at rather cheap prices, that truck transport started developing. With the rising cost of the conventional modes of transport and the development of permanent hard surface roads, trucks have become increasingly popular during the post-War years and are gradually replacing other forms of transport like animal haulage, bullock carts, forest railways and tramways, and even railways on comparatively smaller hauls wherever suitable roads exist. In some parts of Jammu & Kashmir, trucks have replaced transport by river. Motor trucks offer the following advantages over the older systems of transport:

(1) Trucks are frequently used to transport timber directly from the felling sites, thus partially or completely eliminating skidding.

(2) Trucks entail relatively low initial and depreciation costs, and are usually the most rapid method of transportation from the stump to the market.

(3) Trucks can be employed economically in places where scattered fellings are being done, investment of large amounts in other means of transport like forest railways and tramways being not possible in such cases.

(4) Lops and tops and other smaller pieces usually left in the forest can often be economically extracted by means of motor trucks.

(5) Timber can be brought in the log form from the forest for sawing in sawmills, thus enabling a much closer conversion. The practice in most of the Indian forests has been to convert the logs at site to reduce transport costs, and this has resulted in a considerable wastage of wood.

Motor trucks require reasonably good roads and fairly level topography. However, in the mountainous regions, trucks can be employed in conjunction with other devices like the tractor and ropeways. In regions having only fair-weather roads, trucks cannot be used during the rainy season. Further, very long hauls are usually not profitable by trucks.

Transportation by Water

The transport of timber by water is the oldest method known to history. Over long distances it is the cheapest method, but it tends to be superseded by tractors, trucks and railways, because these vehicles can often be brought right up to the felling areas and are more expeditious than waterways, and because transport by them entails less damage and loss in transit. All the same, the use of waterways, whether natural or artificial, will always figure largely as a means of transport for timber. In India, water transport of timber includes two different operations, namely, floating and rafting. In floating, the pieces of timber are allowed to drift down with the current of their own accord, and are not under the direct control of men. Rafting, on the other hand, implies the fastening together of timber into compact structures called rafts, which are naviagated down the waterways and even along sea coasts. Floating is practised in those parts of streams or rivers which are too narrow, shallow or rocky, or in which the current is too swift, for the management of rafts. Where rivers are wide and current tranquil, rafting is always employed in preference to floating. It follows, therefore, that floating is usually most common in the upper reaches of rivers and rafting in the lower reaches.

Floating

Both round and sawn timber can be floated provided the timber is sufficiently light. In Burma and elsewhere, log floating is carried on extensively. In the north-western Himalayas, almost the entire yield of timber is exported to the plains by the agency of rivers, the largest output being in the form of sawn sleepers.

Almost any stream can be used for floating scantlings, but logs are more exacting. The suitability of a stream for floating logs depends on the following factors :

(1) The stream must be sufficiently wide to allow the unobstructed movement of the timber, that is, there must be ample room for the timber to turn round and round without getting jammed against the banks.

(2) The stream must be reasonably clear of obstructions, or there must be sufficient water at some season to float the timber clear of obstructions, so as to avoid jams and undue breakage.

In Europe, the work of improving watercourses has received much attention, and elaborate scheme of weir-construction have been carried out, but for many reasons expensive works of this nature are often impracticable in India. In the Himalayas, river improvement usually takes the form of blasting serious rock obstructions. In Burma, the narrow watercourses running through the forests are annually cleared of fallen trees, stumps and debris, while the floating streams outside the forests are often straightened, widened and deepened in order to facilitate the extraction of logs in large numbers. Back-waters and the mouths of side streams, in which timber is liable to collect, can be closed by the construction of lateral booms or palisades across their entrances.

In Burma, the most common practice for teak extraction is to work logs into the numerous streams running through the forest by means of elephants. These streams are usually dry except during the rainy reason, and logs are left lying in them until the monsoon arrives and a spate comes down with sufficient water to float them. If, as is frequently the case, there is insufficient water to float the logs the whole way, elephants are used to help them along until they reach the main floating streams. In fact, elephants are largely employed in all floating operations in Burma to patrol the banks and push off stranded logs and to break up jams. All logs which fail to get down to the large floating streams or depots during the first year's floating season have to wait till the following year. In the meantime they have all been placed parallel to the banks so that they are ready to start on their down-ward journey when sufficient water arrives. Sometimes it takes many years for logs to reach to timber depots in Rangoon, and logs arriving at depots with hammer marks ten years old are not uncommon. In some districts, logs are often buried in the silt of the floating streams, and when floods occur teak logs are sometimes carried far and wide over adjacent country. Cases are not uncommon where

many thousands of teak logs have been completely buried in areas well away from the floating stream, but the improvement of floating streams has been a special study for many years in Burma, more especially along the plains below the Pegu Yoma mountains, and floating is now conducted on far more scientific lines than was the case some years ago.

In Assam, large logs of species too heavy to float by themselves are brought down from the Lushai and Manipur hills by attaching to them bamboo floats, one float on each side. They are then allowed to drift down uncontrolled until the boom is reached. The same practice is seen in Burma and parts of India, e.g., Kerala, Mysore, when a valuable species is too heavy to float by itself.

In the Himalayas, both sawn timber and logs are floated, but the number of rivers suitable for log floating is restricted, owing to the unfavourable nature of the head-streams on which the majority of the forests are situated. The floating of logs and scantlings in the Himalayas is described below.

(1) *Logs.*—The usual practice is to launch logs on rising water any time before the rains, so that the fullest advantage can be taken of the high water to carry the logs safely over obstructions. Logs and scantlings should not be floated at the same time, as the water requirements of each are different and logs would very seriously damage scantlings in transit. Scantlings are usually launched at the end of the rains. By launching logs at the beginning of the floating season, some logs undoubtedly get carried down beyond the limit of river operations as the booms are not kept in position in high water, but comparatively few get past, for at all the catching depots there are swimmers on inflated buffalo skins who are constantly on the watch for drifting logs. The logs drift down by themselves, and little money is spent on working them down. A small 'sweeping' party is usually employed on re-launching stranded logs and, during the winter, logs which have been left high and dry above the normal flood level are rolled nearer the stream and are automatically re-floated as the river rises. In this case also logs often take years to reach the sales depots, but losses in transit are surprisingly low when averaged out over a number of years.

(2) *Sawn timber.*—Floating sawn timber comprises two quite distinct operations ;

(i) Floating in small side-nullahs, or 'telescopic' floating.

(ii) Floating in the main streams, or 'sweeping'.

Telescopic floating (Fig. II-12).—This operation involves the extraction of sleepers and scantlings down narrow side-streams, characterized by rocky and tortuous beds, and with a great variation in gradient. During the dry weather the water in these streams may be reduced to a mere trickle, while even during the rains the flow is still often insufficient to float scantlings over the numerous obstructions. Under such conditions, ordinary floating is impossible, at any rate throughout the greater part of the stream, and telescopic floating is resorted to. This operation consists in making the whole stream floatable by constructing, with the scantlings themselves, rough slides or chutes over or round all the obstructions. Such a slide is locally known as a *pathru.* An open framework of scantlings is built between and over the boulders in such a way that a trough of scantlings placed lengthwise, side-by-side, can rest firmly on it. Depending on the length of the obstruction, the chute may consist of any number of sections with their ends overlapping. If necessary, the stream can be partially dammed at the head of each length of *pathru* in order to cause a sufficient flow of water. Generally, a pool has to be made at the lower end of each length as well, so that the scantlings may be discharged into deep water and escape end-on damage.

Scantlings may also be passed over quite high water-falls by constructing a framework, which will carry a *pathru* from the lip of the fall at a gentle slope to a point some way below the fall.

Pathru construction often begins from the launching depots and is extended downstream, scantlings being floated to the head down the part already constructed. The banks of those stretches which do not require *pathru* are lined with scantlings to ensure smooth floating throughout. When all the timber has been launched, the *pathru* is progressively broken up from the back and floated to the head, which is continuously extended downstream. In this way the whole *ghal*, which is the local name for one complete unit of extraction in floating operations, gradually moves down to the main stream, into which it is discharged.

Fig. II—12. Telescopic floating.

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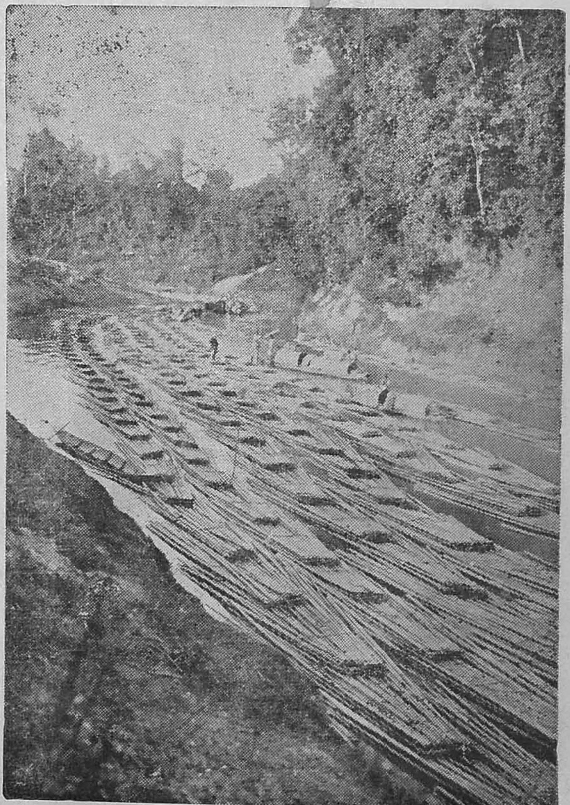

Fig. II—13. Bamboo Rafts.

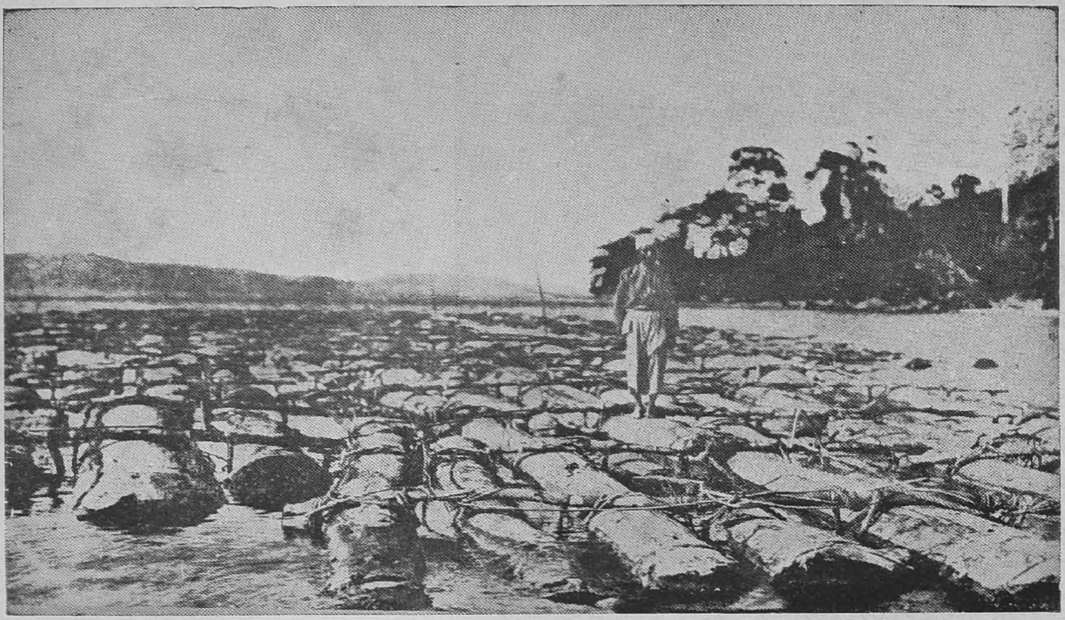

Fig. II—14. Log Rafts in Andaman.

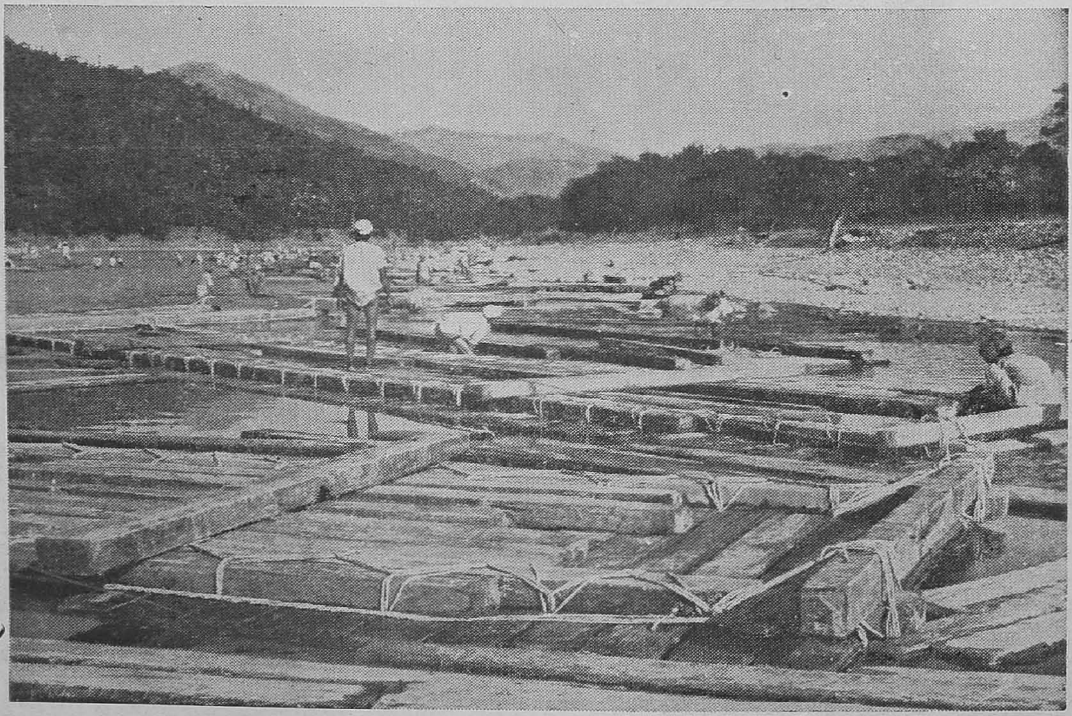

Fig. II—15. Sleeper Rafts ready for despatch

The disadvantages are:

(1) In spite of careful supervision and precautions, there is bound to be some end-on damage to the timber.

(2) There is a limit to the steepness of the nullahs in which this system can be employed. This depends on a number of factors which need not be discussed here.

(3) Should there be a sudden spate, the whole *ghal* is at the mercy of the water and rocks, and the timber may be very seriously damaged.

Generally speaking, telescopic floating is best employed in long nullahs of easy to moderate gradient, where manual carriage and wet slides would be too expensive and the slope insufficient for the employment of ropeways. But Himalayan nullahs are so variable in nature that telescopic floating has sometimes to be combined with wet slides, or ropeways, or even with both.

Sweeping.—In the main floating streams the timber floats down with the current, but a very large number of pieces always become stranded on obstructions such as rocks and sand-banks, or are caught up in backwaters. Gangs of workers are then formed into a sweeping party, which is employed in re-floating this timber. The main party is composed of small gangs, some of which are posted ahead of the main sweep at points where scantlings habitually get stranded in large numbers. Their duty is to keep scantlings moving and to keep the jams as small as possible. The main party works at the back of the *ghal*, and sweeps all timber left behind so as to leave a clear river behind them. A number of men with inflated buffalo skins, who constitute the sweeping party, swim out and re-float all timber stranded in places that cannot be reached by the men working along the banks. As the timber begins to arrive at the boom, the speed of the sweeping has to be carefully regulated in order to avoid forcing so many scantlings on to the boom that it is in danger of breaking. At the same time, sufficient timber must be delivered daily to keep the catching labour at the booms fully employed.

The correct timing of launching in floating operations is a matter of utmost importance and various factors have to be taken into consideration. The sooner the timber is delivered at the sales depots the better are the prices that are likely to be obtained. On the other hand, timber can be floated only when water conditions are fairly safe, or much of it will be carried away and lost. Other considerations, such as the necessity of helping all timber past some cataract or other obstruction before the water starts falling too low to carry the timber over safely, may necessitate even more accurate timing. In side-nullahs, in particular, where telescopic floating is contemplated, too early launching, before the rains are really over, may result in disaster, while undue delay may involve the belated arrival at the sales depots of the whole outturn for the year.

Both telescopic floating and sweeping are done on contract, skilled labour from special districts being recruited. Before launching, the timber in all depots is carefully checked in the presence of the contractor, who is required to give a receipt for the same. Although the contractor is then responsible for all the timber taken over, yet the floating operations are carefully supervised by the forest staff where departmental extraction is practised. The contractor is paid on the quantity of timber he delivers at the boom, and a clause in the contract binds the contractor to pay for any timber lost in transit in excess of a certain fixed percentage—usually 5%— of the timber handed over to him. The whole operation of floating concludes with an enumeration, during the winter, of all the timber left behind. This is stacked above high-water level, ready for re-launching the following floating season.

The average speed per day of timber in telescopic floating is 200 to 400 metres, and that for floating in main streams in the Himalayas 1.5 to 3 kilometres, but these speeds vary considerably, depending upon the terrain and water conditions. The cost of telescopic floating per B. G. sleeper is approximately Re. 0·10 per kilometre and that for floating in the main streams Re. 0·30 per 100 kilometres.

RAFTING

As has already been explained, rafting of timber can only be carried on in waters which are free from rapids and serious obstructions, and in the case of rivers, where the channel is sufficiently wide and the speed of the current moderate. In the large rivers having their origin in the Himalayas, such conditions do not ordinarily exist until the rivers have debouched into the plains. In Burma, and some parts of India, rafting begins as soon as the rivers are sufficiently large and free of obstructions

Bamboos, logs and scantlings (Fig. II—13, 14 & 15) are rafted; not infrequently other forest produce, such as grass, is brought down the rivers on timber rafts.

Boom

Before rafting can begin, it is necessary to catch the freely floating timber by erecting some sort of a barricade across the river called a *boom*. A boom is a contrivance, usually of linked timbers, for arresting the passage of singly floating timber down a stream from its upper reaches with the object of collecting it along the bank for onward transport by road, or making up rafts for further collective floating under direct supervision to timber markets in the plains or for preventing timber from floating into back waters.

A boom may be either (i) Permanent or fixed, or (ii) Temporary or floating. In Europe, fixed or permanent booms are used which involve considerable amount of constructional work and expenditure. However in India, due to great fluctuation in the volume and speed of the current and largeness of most of the floating rivers, only temporary floating booms are erected. These are kept in position from about the beginning of October to about the middle of May, that is during the period when the current and volume of water are within reasonable limits.

Selection of site for a boom.—Proper selection of site for a boom is of great importance. A good site may considerably reduce the direct strain on the boom and ensure its stability and also facilitate handling of timber collection and rafting operations.

An ideal boom site should satisfy the following conditions :

(1) The stream should be as narrow as possible to facilitate control, reduce expenditure and minimise danger of breakage.

(2) The stream current must be slow; preferably below a bent.

(3) Shallow water should be available along the banks for tying up the rafts.

(4) Enough high bank should be available on either side for stacking of timber at times of flood and fixing of anchors for the main cable and guy-ropes.

(5) It should be just outside the foot hills where the stream debouches into the plains and below which there are no obstructions, boulders or rapids.

(6) As far as possible, it should be near a motor road, railway station or a market to facilitate disposal of timber.

Types of Boom

There are many varieties of booms. In Burma, the usual type consists of logs placed end to end and fastened together with short chains or wire ropes passed through the drag holes. Where extra strength is required, single logs are replaced by bundles of three bound together side by side. Another type consists of long canes twisted together to form cables. In parts of Assam, ropes of twisted coir or cane are used.

In Himachal Pradesh and Uttar Pradesh booms are constructed mainly of sleepers which are fastened together in sections, either by bolts or by lashing with wire ropes, or by both. Such booms, from the point of view of design, are of two types:

(a) Two-way or V-shaped boom.

(b) One-way or Single-arm boom.

Where shallow water is available on either bank for raft making and/or facilities of road transport exist on both banks, a two-way boom is economical. Typical example of a two-way boom is the one on river Beas at Dehra Gopipur in Himachal Pradesh. Booms on river Yamuna at Dakpathar and on river Sarda near Tanakpur in Uttar Pradesh are examples of a more elaborate type of one-way boom.

Constructional details of each type, with special reference to examples quoted above, are briefly described below:

Two-way boom

Fig. II-16 illustrates the plan of a two-way boom. The boom consists of two arms made up of 3.66 m (12 ft) fir sleepers, forming a 'V' shape. Each arm is about 43 cm (17 inches) wide on the top face and 25 cm (10 inches) deep. The arms are made by placing three sleepers side by side on edge and staggered in such a way so as to break the joints (overlap being 1/3 length of a sleeper), as shown in Fig. II-17. The sleepers are fastened together by means of iron bolts passing through the centre of 25 cm face of the arm, bolts being placed 1.22 m (4 ft) apart throughout the length of each arm. The vertex of 'V' should be at a point where current velocity is maximum, which is seldom the middle point of the river, and as such the lengths of the two arms are invariably different. The arms make an angle of about 40° at the vertex.

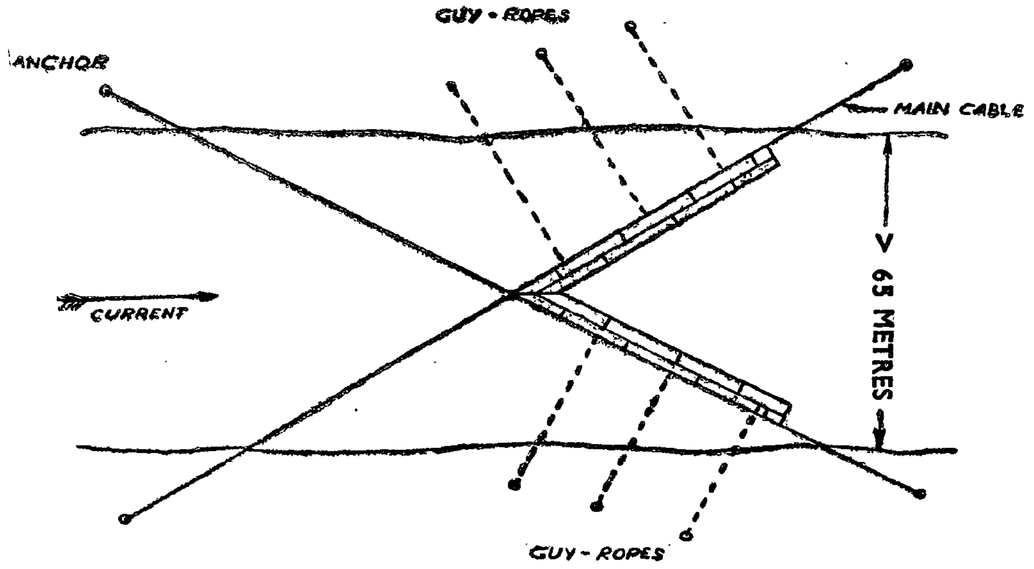

Fig. II—16. Plan of a two-way boom.

The main cables are of 10 cm S.W.R., 6/7 construction with hemp core. They run along the inner side of the boom arms passing through the bolt eyes and anchored on the banks. After crossing the vertex of the boom the cables are taken upstream below the surface of the river in line with the boom arms

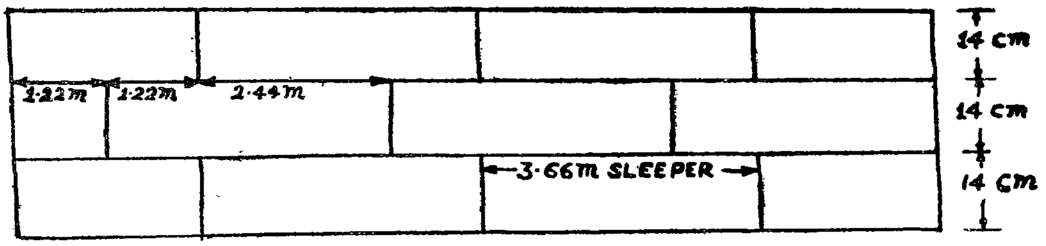

Fig. II—17. Plan of a part of the boom arm. (Two-way boom at Dehra Gopipur).

A number of guy-ropes are attached to the boom arms, at interval of 8 to 15 metres apart, and so anchored on the banks as to form right angles with the boom arms to give them rigidity and maximum support to withstand the impact of the intercepted timber. The guy-ropes are of 7 to 8 cm S.W.R., 6/7 construction with hemp core. All the ropes should be uniformly tensioned.

The anchors for the main cables and the guy-ropes on either bank are usually of picket type. Each anchor is made of three B.G. sleepers, one in the front and two at the back. The anchors are buried in the ground up to half of their length at a angle of 30° to 45° and not upright. Both the main cable and the guy-ropes are tensioned with a winch giving four rounds at the anchor and then secured by bull-dog grips.

The boom at Dehra Gopipur is installed by the rafting contractor in the first week of October every year and dismantled by 31st May of the following year. The contractor bears the entire cost of

installation of the boom, except for timber which is supplied by the department and is replaced after every three years. It is estimated that a some of Rs. 30,000 to Rs. 35,000 is required, to set up a new boom (including cost of timber, material and labour) across an approximate 120-metre river span. Labour cost alone amounts to about Rs. 700 for installation and Rs. 300 for dismantling.

About 2,50,000 pieces of timber of all sizes are collected annually at this boom.

One-way boom.

An ordinary one-way boom for smaller spans is similar to the two-way boom in construction except that it has only one arm instead of two. However a more elaborate construction has been in use for decades on Yamuna river at Dakpathar and on Sarda river near Tanakpur (Fig. II-18). The two booms are identical in design, and each one consists of two parts:

(i) Boom proper, and (2) Log line or *line dori.*

(1) *Boom proper* consists of a strong frame work made up of a number of sections, depending on the span of the river and the inclination of the boom, which are fastened together. Each section (Fig. II-19) is 3 m × 1·83 m × .38 (10 ft. × 6 ft. × 15 in), whose two edge pieces, forming the sides, are of deodar sawn timber, 3 m × 38 cm × 12·5 in cm size. The ends of these are shaped to form a scarf-joint, about 45 cm long, so that when fitted together a continuous surface is presented to the floating timber imp-inging on them. The edge pieces are strutted apart by five (sometimes six) cross pieces, 1·38 m × 15 cm × 10 cm each, which are dovetailed into the side pieces. Vertically below the end cross pieces are placed two tie pieces, 1·38 m ×10 cm × 10 cm each. Three wooden cleats, 30 cm × 10 cm × 3 cm, and three iron tie rods, 1·88 m long and 2 cm in circumference, are fixed one on either and one in the centre

Two planks 25 cm × 3 cm in section are fitted in the centre and along the entire length of each section to from a foot-board for movement of labourers. A wooden projection 3 m × 5 cm × 5 cm. called *beading*, is also nailed along the upstream side of the section to withstand wear and tear by the impinging timber.

Holes are bored in the spliced ends of the section and, when one end is fitted on to the other, thin wire ropes are passed through these holes and around the scantlings to prevent the several sections from opening apart. Four stout eye-bolts are fixed into the sides of each section to on either side, through which pass two main cables 7 cm in circumference, one on either side, running from one anchorage to another on either bank and passing through all the eye-bolts, and thus linking all the sections into one compact floating structure. Each section costs about Rs. 350, including the cost of timber, labour and other material.

The boom is maintained in a slanting position, making an angle of about 30° with the banks, by guy-ropes of 4 to 5 cm S.W.R.

By lengthening or shortening the guy-ropes the inclination of the boom can be adjusted to the desired extent.

(2) *Log line* or *line dori* consists of a line of logs fastened to the last section of the framework and reaching from it to the other bank of the river for economy in expenditure. The logs are fastened together by wire or grass ropes which pass through holes bored in the logs. Log line is also kept in position by means of guy-ropes anchored on the river bank to the trees or windlasses.

The main timber framework of the boom lies across the main portion of the stream, whereas the log line is placed in the slack water and forms a bay where the floating timber, after being deflected by the main framework, is collected.

When the boom is dismantled, the boom sections are taken out and kept in the nearest open go-down for use during subsequent years. With proper maintenance these sections can serve for a long time.

Rafts (Fig. II-13, 14 & 15)

In Burma, the rafting of teak logs is carried out on a large scale and the construction and naviga-tion of the rafts required considerable skill. Briefly, the most common type of raft consists of a number of sections which are fastened head to tail with canes, chains or ropes. Each section consists of 16 to 20 logs, laid side by side with the length in the direction of the stream. The logs are fastened together by means of canes or chains passed through the drag-holes. In each section logs are, as nearly as possible, of the same length, the largest logs being placed in the leading sections. The whole raft is strengthened and protected by single long logs fastened along the sides of the raft, breaking the joints of the section

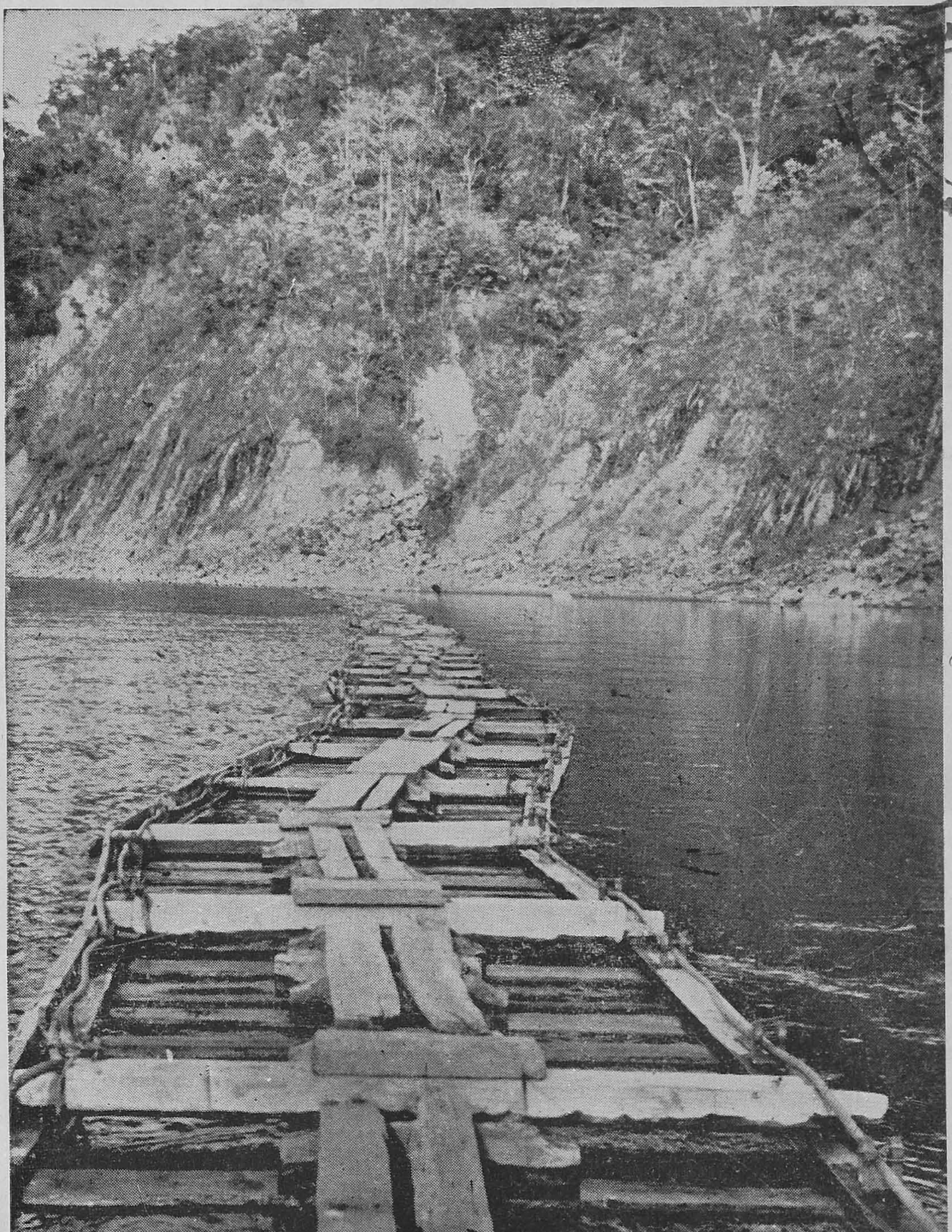

Fig. II—18. Timber boom across river Sarda showing details of construction.

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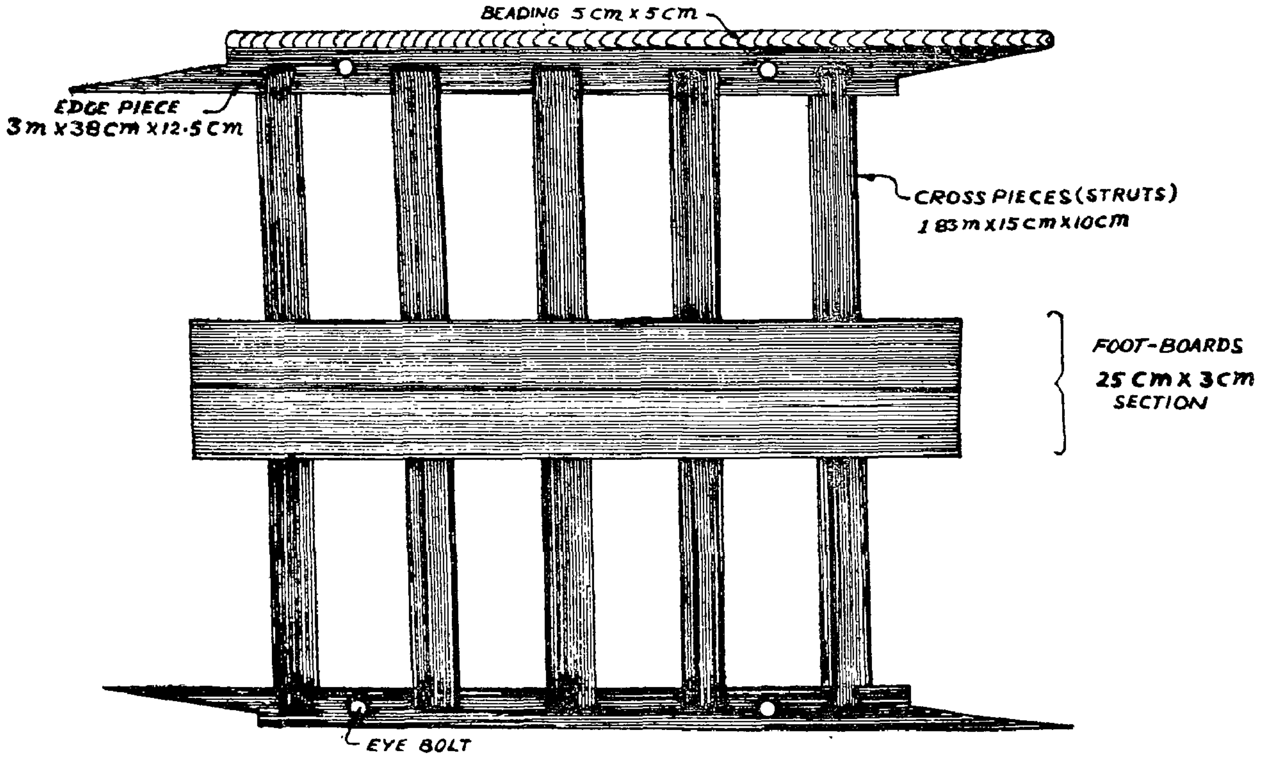

Fig. II—19. Plan of section of the one-way boom at Dakpathar.

Rafts are managed by crews of four or five men who live in small bamboo or grass huts built on the raft. Guiding is done by means of long oars. Non-floatable timbers are sometimes rafted by means of floats made of bundles of bamboos or of some light timber such as maina (*Tetrameles nudiflora*) or semul (*Salmalia malabarica*), and it is not uncommon to find some non-floatable logs attached to large rafts of teak or even tied on top of the rafts. Occasionally, logs of some heavy but valuable species are rafted by means of boats to which they are fastened, but this practice has its limitations.

All teak logs rafted in Burma have been standing as girdled trees for two years. Green teak will not float, but after a teak tree has been standing for two years as a dead tree, the timber is floatable. If it were not for this significant fact, the extraction of teak in many parts of Burma would be well-nigh impossible or, at the best, very expensive. A very careful check is kept on all teak rafts, and all the logs in a raft are measured individually at several points before the rafts are finally taken over at the sale depots.

In Himachal Pradesh, log rafts (rare nowadays) are very similar to the teak rafts described above. One difference is that where the current is swift a log is trailed behind the raft on a rope to act as a brake. Large logs of over 2.4 m (8 ft) girth are usually taken down in rafts, separately from the smaller-sized logs, in September, when there is more water in the rivers.

All timber arriving at the boom is caught by men swimming on inflated buffalo and goat skins, and is brought to shallow water, where it is made up into rafts. Rafts vary in type on different rivers. On the Sutlej and Yamuna rivers, sleepers are placed two-deep in rows, the length of the sleepers being at right angles to the direction of the river. Across these, two double rows of sleepers are then placed lengthwise. The pairs of sleepers in the rows are bound together, and also to the sleepers placed lengthwise across them, by ropes made of grass. These rafts are taken down by two men who use long poles for guiding the raft and fending it off the banks. For purposes of check and control of the rafts while in transit, intermediate check depots are established between the booms and the sale depots. The men in charge of the rafts are given chalans showing the details of the scantlings in their rafts. These chalans are checked with the rafts at each intermediate depot. The work at the boom and rafting, as well as the salving of timber stranded below the boom, is invariably done on contract.

REFERENCES

1. Anon. 1932 Departmental Exploitation; *Punjab Forest Leaflet* No. 9. Suptdt., Govt. Printing Press, Punjab, Lahore.
2. Asthana, M. N. 1963 Safety Measures in Logging; *Journal of the Society of Indian Forester*, Vol. III, No. 1, March, 1963.
3. Brown, N. C. 1958 Logging; John Wiley & Sons, Inc., London.
4. Fernandez, E. E. 1891 Notes on the Utilization of Forests; Thomason Civil Engineering College Press, Roorkee.
5. Koroleff, A. 1954 Full-Tree Logging; Pulp and Paper Research Institute of Canada.
6. Masani, N. J. 1962 Lecture Notes on Forest Booms; Manager of Publications, Delhi.
7. Niranjan Sing, Asthana, M. N. & Bhatia, D. N. 1966 Modern Logging Tools, Equipments and Techniques as introduced at the Logging Training Centre Batote; *Indian Forest Records*, Vol. 1, No. 1. (Logging).
8. Ram Parkash 1955 Lecture Notes on Forest Utilization I for Forest Ranger Students, Dehra Dun
9. Rodgers, Charles Gilbert 1902 A manual of Forest Engineering for India Vol. III; Superintendent, Government Printing, India.
10. Troup, R. S. 1913 Indian Forest Utilization; Superintendent, Government Printing, India.
11. Trotter, H. 1940 Manual of Indian Forest Utilization; Humphery Milford, Oxford University Press.
12. Wackermann, A. E. 1949 Harvesting Timber Crops, McGraw-Hill Book Company New York.

CHAPTER III

STORAGE

The places where wood or other forest produce is stored are known as 'depots'. Although for in some parts of India depots for the sale of minor forest produce exist, the most important depots are for timber and fuel. Depots may be classified broadly in to forest depots, transit depots and sales depots. Forest and transit depots are usually of a more or less temporary nature. Forest depots are intended for the collection and checking of timber (or other forest produce) prior to its despatch from the forest. Transit depots are those in which the timber has to be stored while still on its way to final destination. Sales depots are those in which the timber is stored pending final disposal by sale and in which the sales take place.

Depots may be further classified under land depots and water depots, both of which may be either transit or sales depots. A land depot generally implies a site used for storing wood transported by land. A water depot, on the other hand, is used for the storage of wood transported by water.

WATER DEPOTS

Water depots are of a special nature, and may be briefly considered here. They may be established in a river, in still water, or on the sea-shore.

River depots are always attended with some risk owing to sudden rises due to floods, and are unsuitable for long storage of timber. A place should be selected where the current is slack, a backwater for choice, and the logs should be enclosed by a boom, usually formed of logs chained together end to end. The bank should be stable, so that stout posts may be fixed at intervals for the mooring of rafts or smaller lots of timber; specially firm posts are required for fixing the boom.

Depots in still water may be either natural lakes or ponds, or may be artificially constructed, the water being admitted by a channel leading from the floating stream or river down which the timber has been transported; the channel should be sufficiently wide and deep to allow the timber to be floated into the depot.

A sea-shore depot should be well sheltered, and should not be exposed to the open sea. The beach should have a gradual slope. The timber should not be stored for any length of time in the water owing to the risk of marine borers. There is a typical sea-shore depot at Port Blair in the Andamans; it is sheltered from monsoons, and is situated on a low shelving beach, the water at low tide being nowhere more than a foot or two in depth. There is another sea-shore depot in Beypore near Calicut (Kerala), to which the teak from the Nilambur forests is brought by rafting along the Karumpuzha river for storage and sale.

LAND DEPOTS

A land depot should be so located as to provide for convenient ingress and egress. Land depots will be described under transit depots and sales depots. Forest depots are essentially of the nature of transit depots, and are therefore not dealt with separately here.

Transit depots

Transit depots are used for the collection and checking of land-borne timber, and for the catching, collecting, examining, and rafting of river-borne timber. On main export lines these depots may have permanent sites; elsewhere the sites have to be selected afresh as and when the felling areas change.

Where the disposal of produce is by the royalty system, depots have to be established for the purpose of counting, measuring and checking material removed by the contractor. In such cases, it should be ensured that all produce from the forest is removed only by those routes which pass these 'check

depots' ; in accomplishing this it is often necessary to establish more than one such depot in each felling area, as it is otherwise impracticable to check the produce in the forest. In the check depots, all that is necessary is that the timber or other produce should be stacked in an orderly manner so as to facilitate rapid check.

Where timber is extracted departmentally, strict control is maintained throughout the whole line of transportation, from the stump to the sales depot, by means of a careful system of timber accounts, all arrivals and disposals of timber being entered in the prescribed forms, whatever the method of transport or the nature of the depot may be.

The following are the more important conditions that have to be fulfilled in the case of transit depots :

(i) Timber should not be stacked in the sun as this is bound to start rapid surface drying and cracking; if stacking in the open is unavoidable, the tops of stacks should be covered with a layer of grass or earth, about 10 cm deep, and the stacks placed as close together as possible so as to give side protection to each other.

(ii) To facilitate checking, all timber should be sorted and stacked by species and sizes; the stacks should be numbered serially, and the number of pieces and the quantity of material in each stack should be entered in the depot list and written on the stack with paint or coal-tar.

(iii) Where a large depot borders on a public road, a notice prohibiting smoking should be posted and a chowkidar (watchman) maintained. In some localities, a chowkidar may be necessary in any case.

(iv) In the hills, launching-depots on the banks of floating streams must be located well above the highest flood level. The site must be on stable ground, safe from falling rocks and stones. Other things being equal, it should be so situated that the timber can be speedily and safely launched in a floating season.

(v) Where transport to and from a depot is by land, sufficient space must be allowed for the free movement of vehicles or other forms of transport.

Depots, that are to be retained in the same place for any length of time, should be inspected and checked periodically and deficiencies reported immediately.

Sales depots

Sales depots are maintained for the storage, sale and issue of timber. The sites are generally permanent and most often the property of the Forest Department. They should, therefore, be well demarcated and properly fenced or walled.

As regards the site for a sales depot the following factors have to be taken into consideration :

(i) The site should be close to main lines of transport by road, rail or sea, to facilitate further transport to consuming centres.

(ii) It should be sufficiently large to accommodate the maximum quantity of timber expected to be stored at any time, with scope for possible extension in the future.

(iii) Trees are desirable for shade, and if not already present on the site should be planted up to accord with the pattern of timber storage.

(iv) For sawn timber, valuable woods like sandalwood and fuelwood, as also for charcoal and most kinds of minor forest produce, sheds will be needed for the protection of the material. The aeration in the sheds should be conditioned to suit the materials. While for wood in general and most minor produce, free ventilation is to be ensured in order to minimise fungal damage, for sandalwood and other produce, which lose considerably in value on drying, ventilation should be kept at the minimum.

(v) The site should be well-drained. A damp depot always results in the rapid deterioration of timber from fungal attack, besides making the handling and transport more difficult owing to the soft ground.

(vi) Adequate facilities for the coming in and going out of timber should be provided.

(vii) in river depots, the landing of timber being often a very slow operation the frontage along the stream should be adequately long, so as to enable simultaneous landing over long stretch and clearing the timber from the boom as fast as it arrives.

Management of Depots

Every depot should be in charge of a responsible official, whose rank will depend on the importance of the depot. The control of transit depots has been dealt with earlier, and attention will be confined here to sales depots only. Details of management vary in different localities, but the following are given as general observations.

Lay-out

Depots should be divided into separate plots for each species of timber. Different classes of timber, such as sawn timber and logs of varying sizes and grades, should also ordinarily be stored separately, each species plot being suitably divided for the purpose. The various sub-plots or compartments in a depot should be separated by passages sufficiently wide to afford easy inspection, and it is usually necessary to provide one or more broad tracks to allow vehicles to pass through. In the case of a depot situated on a river, logs should be stored where they would require the least amount of dragging.

Stacking

Subject to the provision of facility for inspection, stacks should be as close as possible for the sake of economy in spacing. Logs should be arranged in neat lines by species and classes. Should it be necessary to pile them, care should be taken that only logs of the same classification are put together, and the details of their measurements should be given on the ends of the logs. It is of the utmost importance not to expose sawn timber to the sun for longer periods than can be helped. This class of timber is usually stacked in piles of one hundred pieces or some other convenient number, and in order to afford protection from the sun to the ends of the scantlings there should be an interval of only about 0.6 m between the ends of stacks. Not more than two scantlings in each stack should be in direct contact with the ground. Fuller information on the subject of stacking timber is given in Chapter XIV.

Measurement, classification, booking and making lots

As soon as a consignment arrives at the depot, the timber should be measured, classified and numbered, and the particulars entered in a register of receipts. The importance of accurate classification cannot be overstressed; well-graded timber will always sell better than timber that has been carelessly classified. The classified timber is stored in convenient lots for sale.

The following rules are important, and should be followed in all depots :

(1) Never place good timber and inferior timber in the same lot.

(2) Do not attempt to hide defects as the purchaser is quite sure to discover them.

(3) Butts should be laid one way in a regular manner, and logs of equal size lotted together.

(4) Lots of approximately equal size and value should be made.

(5) Abide strictly by the depot classification, which should be hung up for public inspection.

(6) All lots should be numbered and accurately measured and booked so that there can be no argument or confusion.

Clearance

Sold timber should be removed from the depot by the purchaser as soon as possible. Purchasers should not be permitted to use the depot as a convenient place for storing the timber they have bought. If such storage becomes unavoidable, special plots should be set aside at one end of the depot for leasing to the purchasers concerned on adequate payment, but this practice should not be encouraged.

Stock-taking

Depots should be checked and the books balanced at intervals of a few months and the results reported to the proper authority.

Fire and theft

Adequate measures to protect depots against fire and theft must be taken. The need for appointing chowkidars in depots has already been mentioned. Chips and refusewood must not be allowed to lie about in depots. In forest depots, fire tracing to a sufficient width is an indispensable safeguard. Sometimes, large depots, especially sales depots, are insured against fire in order to safeguard against possible loss.

Insect attack

The following precautions are important :

(1) Avoid unhygienic conditions which promote insect attack. The depot should be kept clean and as free as possible of scraps of wood and bark. Frequent collection and burning of rubbish in the timber yard is a necessity. Grass, weeds and bushes must be removed so as to maintain perfect cleanliness all over the depot.

(2) To avoid termite attack, the timber should be stored raised from the ground, preferably on anti-termite skids, e.g., cement pillars, iron rails, treated wooden pillars, stones, etc.

Fungus attack

The following precautions are suggested :

(1) To reduce end-splitting, which makes for fungal infection, the cut ends may be given a moisture-retardant coating of heavy asphalt or bituminous preparations.

(2) When logs have to be stored for a long time, it would be better to store them in log ponds, as a protection both against fungus attack and against splitting. It is desirable to ensure, by suitable devices, that the logs remain fully submerged in a order to prevent damage to the portions normally exposed in floating.

(3) Free moisture in wood invites fungal infection : storage should be so made as to ensure free ventilation.

(4) Decayed logs are a source of infection; they should be disposed of and should not, in any case, be mixed up with sound ones.

CHAPTER IV
SAWMILLS AND WOOD WORKSHOPS

SAWMILLS

A saw mill is a plant with different types of machinery for sawing logs into planks, baulks and scantlings. Sawing of logs is an essential preliminary to their proper and economical use. Saw-milling therefore forms an important step in wood utilization.

Great advances have been made, since the early days when single boards were sawn of by hand, in the processes employed for converting logs into planks, scantlings and baulks. Speed and economy of manufacture are as essential in saw-milling as in any other industry. As timber is a heavy and bulky commodity, the machinery used to work on it must be rugged enough to resist the incidental wear and tear.

Classification of saw-mills

Saw mills can be classified in several ways according to different criteria. The lay-out relating to the number and type of head saws and their interrelation may give rise to a classification (Band saw-mill, Circular saw-mill, Gang saw-mill, Double band saw-mill, Twin band saw-mill, etc.). Then again, there are large and small saw-mills, and, as the latter may be regularly shifted from place to place, a division can be made into permanent and portable saw-mills. For purposes of this chapter, saw-mills are distinguished under these two types, viz., (A) permanent saw-mills, and (B) portable or semi-portable saw-mills.

(A) Permanent Sawmills

These are usually situated either close to or in cities. Many of them undertake what is known in the trade as "public sawing and machining", i.e., they convert material for cabinet manufacture, joinery shops and allied trades which do not have sufficient milling work to warrant establishing their own mills.

General location of a sawmill

Whatever the size of a sawmill, its proper location is essential if its profitable operation is to be ensured. Even well equipped and well-laid out mills will operate with serious losses if not suitably located.

An adequate supply of logs of suitable sizes and grades should be available within a reasonable distance of the mill location to meet the initial, as also the prospective increased, capacity of the mill. Other factors requiring attention are transportation facilities, labour supply, availability of electric power, good plant site, etc. Other conditions being equal, the sawmill is best located as near the geographical centre of the supply area as possible.

Because logs are heavy and contain much non-utilised weight and volume in the shape of water, bark, slabs, edgings and sawdust, it is usually economical to locate a sawmill near the source of timber. This minimises log-hauling distances, though the haulage to the market may become longer. Where the logs have to be transported over great distances in any event, it is usual to locate the sawmill near the market.

In deciding the location of a sawmill, attention should be paid to transportation facilities required for delivering logs to the mill and moving finished timber to the market. Logs are usually delivered to mill sites by boats, motor trucks or rail.

Siting of the sawmill

After deciding the general location for the sawmill, it is necessary to fix a specific site for the factory. An important factor to be considered is that of size. It should be large enough to accommodate the facilities originally planned and also to provide for future expansion. It should be easily accessible to transportation facilities for logs and converted timber. There should be adequate space for log storage,

either wet or dry. If the converted timber is to be partially dried on the site, the drying area should be well ventilated to facilitate drying. The site should be level and well-drained so that foundations are firm and do not settle. If electric power is required, sufficient power transmission facilities should be available to provide adequate and continuous supply of power.

Mill lay-out

Mill lay-out is concerned with the arrangement of wood conversion facilities on the factory-site. The operation will not be efficient if the several units and equipments are not properly arranged in the manufacturing area. There should be well-thought-out plan for the location of each part of the mill, so that the product passes by an orderly process from one section to another from the time the log enters the mill until the finished products are loaded in trucks for removal. Efficient lay-out ensures minimum expenditure of time and labour on such time consuming jobs as the handling and piling of logs and the disposal of refuse (sawdust, off-cuts, trimmings, etc.). If a waterway for bringing the logs to the mill is feasible, the entrance of the mill should, if possible, be within easy access of the water to avoid excessive hauling. To simplify handling, the breakdown machines should be positioned in such a manner that logs can be handled by these machines as they arrive from the water and the lighter converted material passed through the mill to other machines later.

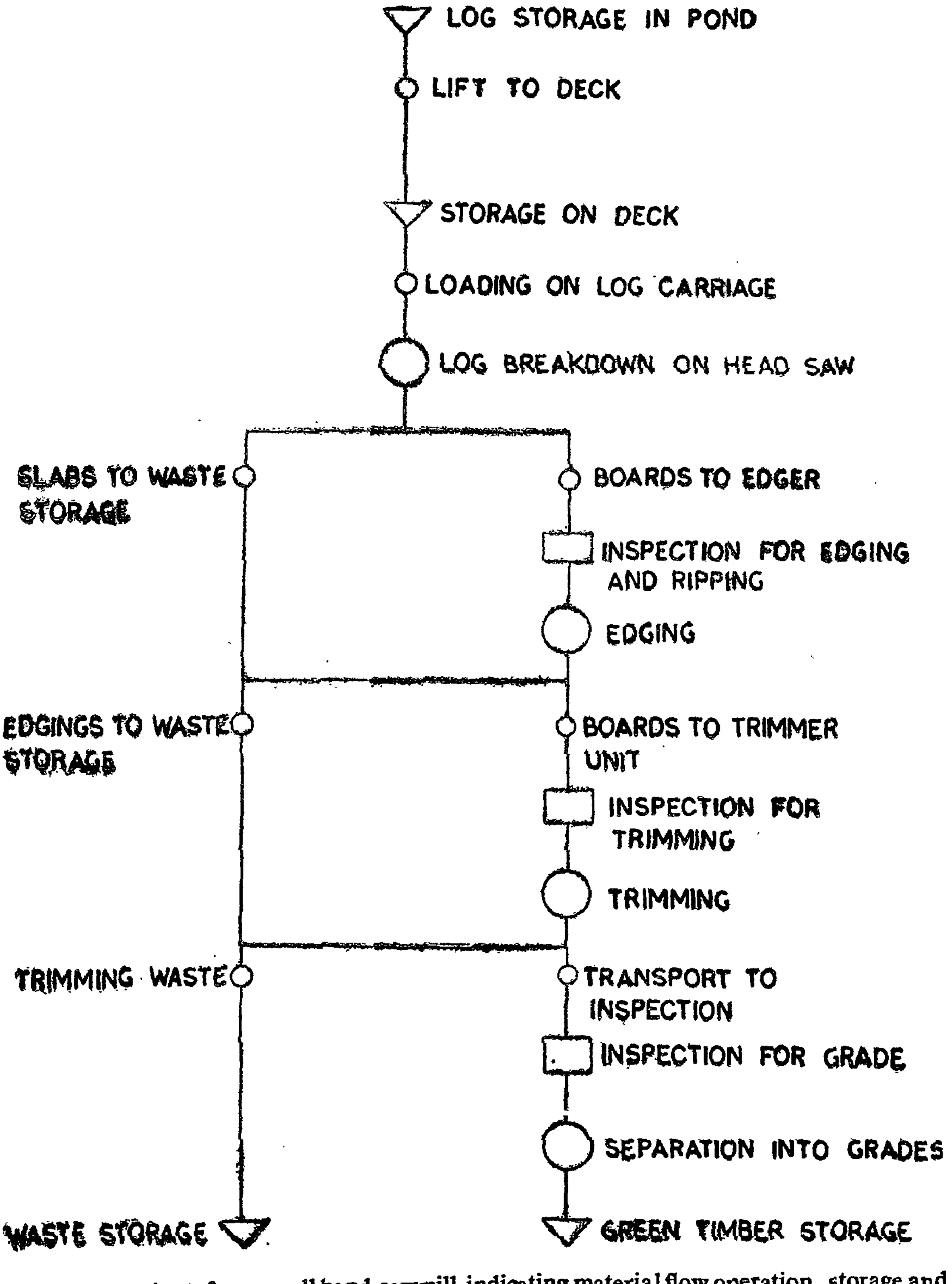

Fig. IV—1. Process chart for a small band-sawmill, indicating material flow operation, storage and inspection. (*Adapted from "Lumber" by Brown & Bethel*).

In preparing a mill lay-out, it is helpful to prepare a process chart covering the operations contemplated. Fig. IV-1 shows one for a small band sawmill.

Legend

○ Operation

o Movement

▽ Storage

□ Inspection

The following sketch (Fig. IV-2) shows two types of sawmill lay-out—Type A for Twin band mill and Type B for Band head saw and horizontal band re-saw:

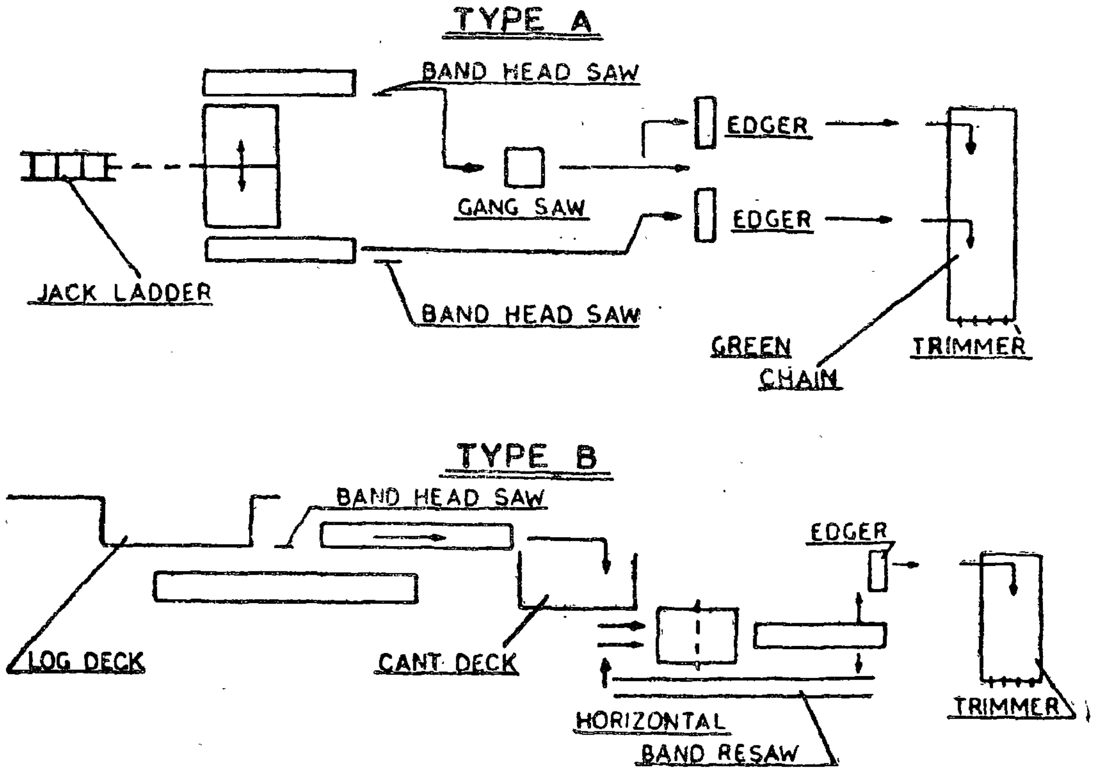

Fig. IV—2. Two types of a sawmill lay-out.
(Adapted from Varossieu, W. W.)

In addition to the floor plan for equipment lay-out inside the mill, a site plan should be prepared to show the relationship between the sawmill building and the log yard or pond, the roads or railway tracks serving the factory, dry kilns and other associated buildings.

Permanent sawmills do not confine themselves to the breaking down of logs into beams, planks and scantlings, but frequently machine material to a point ready for assembling into such products as doors frames, flooring boards, and similar mass-production commodities. It will, therefore, be seen that the lay-out of a mill is governed to a great extent by the work required from it and the millman must, of necessity, consider all points before selecting and fixing his machines in position. In short the object must always be to lay out the mill with an eye to general efficiency for the purpose for which it is intended, combined with speed and good quality of output at the lowest compartible overhead and other charges.

Other requirements of permanent sawmills

Modern mill buildings are usually rectangular, the length being two to three times the width, with good side and top lights and a large entrance and exit at either end to permit logs being brought into the mill at one end and, after going through the machining process, passed out at the other end as finished products. Where steam engines are the prime movers it is usual to instal the boilers in an annexe to the mill.

The handling of timber, both large and small, is an all-important point requiring careful study unless properly organized it will make the production unprofitable. It may be mentioned that most large well-managed mills are provided with tramways, quick lifts, overhead electric hoists, gantries, jib cranes and other contrivances for reducing handling costs and speeding up propuction.

Selection of equipment for sawmills

The selection of machines for the sawmill is a matter for serious consideration, and will depend entirely upon the class of milling to be done and the primary object to be attained. Among the several possible objectives in saw-milling may be mentioned : (i) maximum daily output, (ii) minimum cost of machines and labour, (iii) maximum production of sawn timber from unit volume of logs, (iv) accuracy in timber dimentions, and (v) highest timber grade and value. Not all of these objectives are by any means equally attainbale with any one type of mill or equipment .The mill-man must, therefore, consider carefully which type is best suited to his particular requirements. Initial and maintenance costs have also to be taken into consideration. The latter point is a matter of some importance as some kinds of saws require the continual attention of an expert "Saw doctor" to keep them in good condition, whilst others are more or less foolproof and required very little doctoring.

Power plant

The manufacture of timber requires the use of power. The original pit saws were dependent entirely on manpower for conversion. With the development of the saw-milling industry, mechanical sources of power—steam engines, internal combustion engines and electric motors—have come into wide use.

Steam power.—A conspicuous feature of the saw-milling industry since its early beginnings has been the production of wood wastes as a by product. Though modern technology has found avenues of profitable utilization for much of this material, large quantities of unused wood residues are still produced by sawmills. As this wood waste can be used as fuel for generating steam, steam power has always been popular with the saw-milling industry, particularly for large permanent sawmills. For portable and semi-portable sawmills, steam power is supplanted by internal combustion engines or electric motors. Steam is used to power a saw mill, through the use of steam engines and connected equipment including a system of belts and shafts. It can also be used to generate electricity, which is then used to operate the several items of machinery. The horse power of the engine and boilers will be governed by the intended load, but prudent operators usually instal engines and boilers of a horse power in excess of actual requirements, in order to permit an overload and possibly the introdution of extra machines.

Internal combustion engines.——These are generally used in portable sawmills, and for this purpose range in size from 20 to 100 H.P. Engines with over 100 H.P. may be needed for large mills or where provision for later extension is to be made.

Electric motors.—These are used in permanent sawmills wherever power supply is available. One advantage of electric over steam power arises from the fact that separate motors can be attached to each machine. The self-contained or motorised machines possess several advantages over those driven by means of belts. In the first place the drive is direct and as there is no belting, belt slip is eliminated as also power loss by belt and shaft loads. Further, machines having their own motor and starter are under the complete control of the operator, who can work or stop each machine as and when required, without having to keep a main shaft running for one machine while the others may be idle. This results in economy in running costs and efficiency, and "motorised" machines are rapidly gaining favour in the milling industry.

It is not uncommon to combine electric power with steam or internal combustion engines. The engines are used to run an eletric generator, which supplies the current for running the entire machinery

Power transfer—main shafting and counter shafting

Except where self-contained machines are employed, a main shaft for transmitting power from the prime mover to the machines must be provided. These shafts, to which counter-shafts are usually connected, are fitted with pulleys, of a size suitable for attaining the desired machine speeds, and are preferably situated in pits under-ground.

The diameter of the main shaft depends upon the load to be placed upon it, but no larger shafting than is actually required should be used. The general rule is to instal main shafts of 7.5—10 cm,

diameter for driving machines when they are heavy and many. Countershafts and main shafts for driving light machines may be as low as 6 cm diameter, or even less in some cases, depending on the power to be transmitted.

Wherever possible, it is advisable to run all shafting in roller or ball bearings. This will reduce wear and tear, friction and power demands. A good form of lubricating system must be provided.

The distance between bearing points is controlled by the torsional and bending strains placed upon the shaft by belt tension, speed, and the number of pulleys to be employed. For most lay-outs, the distance between pillars is generally kept between 1.2 and 2.7 m. Speeds of between 250 and 300 revolutions per minute are generally considered adequate for main shafts.

Countershafting consists of any intermediate shaft, or set of shafts, connected up to the main shaft by means of belts. A countershaft has various uses and can be assembled to perform one or more functions at the same time. Several pulleys can be attached to a countershaft, each of which can be arranged to serve a different purpose. By connecting up, either directly or through other countershafts, to a main shaft, it is possible to lay machines in any desired position on a mill floor, and by means of straight or cross-driven belts a forward or reverse motion can be obtained. Economy in floor space is the result of a judicious use of countershafts, which also serve as a method by which to adjust the speed of machines or parts of machines without altering the speed of the main shaft, which should remain constant. Countershafts are frequently fitted with loose pulleys which run free on the shaft, so that when it is desired to bring a machine to a stand still, the belt, which is transmitting the power, is slipped from the fixed pulley to the loose pulley by means of a 'striking' or belt-shifting gear.

Belting

Power is transferred from the power unit to the main and countershafts by means of either a flat belt or a set of V-belts. The several items of equipment are then operated off the shafts by means of pulleys and flat-belt or V-belt drives. To secure efficient power tranmission, sizes of the belts and pulleys must be adequate for the power load to be transferred. If the belt contact area and the pulley size are insufficient, the belt will slip and power will be wasted. The contact area of a belt and pulley is determined by the arc contact of the belt and pulley. If the pulleys are equal in diameter and the belt is tight, the arc of contact is 180°. If the two pulleys are unequal in size, the arc of contact of the smaller pulley will be less than 180°. The smaller pulley will then become the limiting factor in power transmission.

When it is necessary to increase or decrease the speed of rotation in transmitting power from one shaft to another via pulleys and belts, this can be easily effected by varying the size of the pulleys, the diameters of the pulleys being in inverse ratio of their speeds. Pulleys must be properly aligned. They should be kept tight to prevent slipping and consequent loss of power.

Owing to the variation of loads and the high speeds at which belting is run, it is essential that proper selection and care are given to all belting. Various kinds of belts are found in the market, and they are usually made up of leather, woven hair, woven cotton, or rubber. These belts vary in price and quality, and all will possibly give the service claimed for them if properly looked after. It is however advisable, even at a little extra initial cost, to instal the best belts procurable at the outset as they will pay for themselves in the long run.

There are three common methods of joining the ends of belts together, namely, butt jointing, spliced jointing, and staggered jointing. Whichever type of joint is adopted, it is essential to see that one edge of the belt is not longer than the other, as otherwise the short side will run towards the crown of the pulley and possibly give trouble.

Many devices have been used for fastening the ends of belts together, the commonest being wire lacing, hide lacing, and several types of patent fasteners. When fixing new belts, it is a common practice to ascertain the length between the pulley centres and adding half the circumference of each pulley.

All belting should be examined frequently, particularly during monsoon weather when belts have a tendency to contract and become taut when out of use, even overnight. Belts should be kept pliable and should have a good grip on the crowns of the pulleys.

Chief operations in saw-milling

The essential operations in a sawmill are :

(i) Breaking down the log into planks, slabs or baulks.

(ii) Cutting the planks, slabs or baulks lengthwise in a ripping or edging operation, with the object of removing wane, improving the grade, or dimensioning to width.

(iii) Cutting the planks or scantlings across the grain for the purpose of removing defects, improving the grade, or dimensioning to length.

In small sawmills the break-down and ripping (or edging) operations are sometimes performed on the same machine, while larger sawmills employ several machines to perform each of the basic operations.

General Description of Saws

Saws are cutting tools with toothed edges. The various types may be classified into reciprocating, revolving and travelling saws. The first class includes various hand and machine-operated blades, some cutting only on one stroke, others cutting both backwards and forwards. The second class covers the circular saws; the largest circular saws may be up to 3.6 m in diameter. The third class refers to band saws passing around wheels. It is of primary importance in saws that the kerf should be cleared and this depends on the "set", i.e., the side projection or spread of the teeth from the plane of the saw blade. The saw teeth are of varying fineness to suit the nature of sawing involved. Their shape also varies, some projecting forward with straight or curved edges, others of equal angles, and many of special 'M' shapes for crosscutting of logs. In the most elaborate forms cleaning teeth are interspersed with cutting teeth so as to scrape out the sawdust and clean the kerf neatly. In the larger circular saws, the inserted class of teeth is very common. They are held in sockets around the disc with a V-fastening and a springy holder, or with a wedge fixing.

In sawmills, three classes of saws are in common use, viz., circular, and band reciprocating. The circular saw is used for breaking down logs, and for edging, trimming and crosscutting purposes; it is therefore used for both ripping and crosscutting. Band and reciprocating saws are used as head saws or re-saws for ripping logs, cants and slabs.

Saw teeth are of two types, namely, the swage-set and the spring-set. Both types may be used for rip saws, but only the spring-set is used for crosscutting purposes. Swage-set is usually preferred to spring-set as one tooth in the former can do the work of two teeth in the latter. In rip-sawing the wood fibres are cut in the longitudinal direction and are chipped off by the chisel-like action of the teeth, while in crosscutting the fibres are severed in the transverse direcion. Swage-set saws can stand a higher feed than springset saws.

In sawing, the width of the kerf should be greater than the thickness of the saw blade in order to prevent the latter rubbing against the side of the cut and becoming heated due to friction. The swage or spread is usually greater for softwoods than for hardwoods. In swage-set (also termed 'square dress') the teeth are set by spreading the tips to a width greater than the thickness of the saw. In spring-set (also termed 'bevelled dress' or 'briar dress'), the teeth are set by bending them out of the plane of the blade, alternately to each side.

The thickness of a saw blade is denoted by its gauge number (from 0 to 20), each numeral representing a definite fractional part of an inch. The values of the Birmingham gauge (also used for the diameter of wires) are reproduced below ;

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TABLE IV-I

Saw guage equivalents: Birmingham gauge (*Source* : "Lumber", by Bryant)

Gauge No.	Approximate fractional part of an inch	Decimal part of an inch	Equivalent metric units (cm)
0	22/64 scant	0·340	0·864
1	19/64 full	0·300	0·762
2	9/32 full	0·284	0·721
3	17/64 scant	0·259	0·658
4	15/64 full	0·238	0·605
5	7/32 full	0·220	0·559
6	13/64 scant	0·203	0·516
7	3/16 scant	0·180	0·457
8	11/64 scant	0·165	0·419
9	9/64 full	0·148	0·376
10	1/8 full	0·134	0·340
11	1/8 scant	0·120	0·305
12	7/64	0·109	0·277
13	3/32 full	0·095	0·241
14	5/64 full	0·083	0·211
15	5/64 scant	0·072	0·183
16	1/16 full	0·065	0·165
17	1/16 scant	0·058	0·147
18	3/64 full	0·049	0·124
19	3/64 scant	0·042	0·107
20	1/32 full	0·035	0·089

Different kinds of break-down saws, re-saws, etc.

The head saw.—The primary break-down of a log takes place at the head saw. This is the saw which reduces the log into smaller components like cants, planks, etc. Different types are in use, and of these the most common head saw equipment consists of a single circular saw or a band saw. The log, placed on a carriage, passes through the saw repeateldy until it is reduced to the desired components. The log is examined by the sawyer, ar the start and after each cut is made to determine the most satisfactory way to cut it up in order to obtain the maximum grade and yield. The log may be turned many times in the carriage in the process of breaking it down.

The circular saw and band single saw are common installations in Indian saw-mills. The single saw head rig has the advantage of permitting the log to be turned in the process of breaking it down, so as to take full advantage of its grade potentialities. The gang saw, on the other hand, takes a smaller kerf, cuts more accurately and requires less labour for conversion of a unit volume of logs.

The different kinds of head sawas are dealt with below :—

(1) *Circular head saw.*—This became popular with the advent of mechanical power for running sawmills. Originally it was solid-toothed. An early improvement was the development of the gullet tooth which provided for large sawdust chambers. A later advance was the invention of inserted tooth-saw. This increases the life of the saw blade and is relatively easy to maintain. The circular saw is used by a. large number of Indian mills. It is well adapted for small and medium-sized mills. The saw blades may be either of the solid-tooth or inserted-tooth type, the latter being more common. The saw is mounted on a mandrel shaft supported on bearings. The power is supplied through a steam engine, oil engine, or electric motor. The bearings supporting the mandrel may be babit, ball, or roller bearings. While light-weight mills may have babit bearings, the better sawmills have ball or roller bearings. Heavy flywheels weighing up to 300 kg are used to smooth out the operation of the head saw and make it less sensitive to sudden shock loads, such as on the entrance of the saw into the log or on its striking a very hard knot.

Some circular head rigs are equipped with an overhead saw to increase the mill's capacity as regards log diameter.

Circular head saws are low initial cost and upkeep. They are adapted to sawing small and medium-sized logs into timber of the highest grades and of any required thickness. Compared to other head saws, however, they involve the maximum waste in the form of sawdust and are, besides, capable of only medium uniformity of dimensions in the sawn products.

(2) Sash head saw.—The sash saw, which is also called the *gate saw or frame saw,* is a device in which one or more saw blades are secured to a frame (sash), the whole moving to and fro in machines either vertically or horizontally. This is an offspring of the pit saw. The simplest form with a single blade mounted in a wooden frame has already been described in Chapter I under the name *frame saw*, and is in common use for conversion in the Himalayan forests. Sash head saws are not now common in sawmills, though they are said to have been used extensively in the early days of sawmill industry in the U.S.A.

(3) Gang head saw.—The *gang saw* is a logical successor to the *sash saw,* and is defined as a device in which two or more saws are mounted together, either on the same arbor (*circular gang saw*) or in a frame which moves to and fro vertically or horizontally. As the latter type is by far the commoner, the term *gang saw* is often used for *frame saw*, but the usage is deprecated. The most common form of gang head saw consists of several saws mounted parallely on a vertically-operated sash. Unlike band and circular head saws, the log is converted into cants, boards, etc., in a single pass through the mill instead of requiring several trips past the saw. It cuts by means of the series of parallel saw blades which move up and down with the frame as the wood is slowly fed through the machine. Typical gang saw turn out well-sawn timber, more accurately than band or circular head saws and with a minimum of waste, and are favoured in European sawmills.

The circular gang saw is a simple machine designed to convert small knotty logs into timber. It consists of a battery of circular saws mounted on a single arbor and spaced for cutting 2.5 to 5cm thick boards. This type of head saw is not much in use.

(4) Band head saw.—The band saw consists of an endless band of steel, toothed on one or both edges and mounted on two wheels, one of which is above and the other below the cutting field. When toothed on one edge, it is called a *single-cuting band saw*; when toothed on both edges for sawing on both the forward and backward travel of the carriage, it is called a *double-cutting band saw*. Power is applied to the lower and heavier wheel which acts as a flywheel, driving the saw downward through the log as it is fed on the carriage. It has superseded the circular saw as a head saw in many large sawmills, because it cuts a lighter kerf and is more accurate. Band saws are, however, much more delicate in their reaction to sawing procedure than circular saws. If a log is forced into a band saw too rapidly, it may rend the saw entirely from its wheels, whereas the only reaction of a circular saw to an excessive feed rate is usually the slowing down of the saw and a decrease in the efficiency of sawing. Also, band saws are much more susceptible to damage from stones, nails and other hard extraneous material in the wood or bark.

The size of a band saw is usually designated in terms of the diameter of the wheels; that is, a 2-m band saw would have wheels 2 m in diameter.

Single-cutting band saws are more commonly in use as head saws than double-cutting ones. Theoretically, the latter should conduce to save time as they cut the logs on both the forward and the backward run of the carriage, but in actual practice the advantage is not much.

Re-saws.—The function of the re-saw is to reduce cants, heavy slabs and other large sized timber produced at the head saws into smaller or thinner pieces required for various uses. Where the volume of logs converted is large enough, only the major break-down is accomplished on the head rig and the remaining sawings is done on one or more re-saws. The head saws rarely cut material thinner than 5 cm; boards of 2.5 cm thickness are invariably produced by passing thicker material through re-saws.

Re-saws are of several categories : gang re-saw, circular re-saw, single vertical band re-saw, double vertical band re-saw, horizontal band re-saw, and double-cutting pony band saw. Nearly all modern re-saws are the different forms of band re-saws which may operate in either a vertical or horizontal plane.

The Edger.—The edger is a machine used in sawmills to square-edge waney timber and also to rip timber. Its primary functions are to produce boards with parallel sides and to remove the wane or rounded barked edges as they come from the head saw. Another important function is to divide wide boards into two or more boards of desired widths. A third function is to separate valuable portions of boards from knotty or otherwise low-grade portions. Essentially, the edger consists of a frame supporting a saw arbor with one or more circular saws, feed rolls, press rolls and transmission gear mounted on it. Edgers vary widely in size and capacity. Usually, one of the circular saws is stationary and one or more can be moved laterally on the arbor to permit ripping different widths. Large gang edgers may have up to four or five moving saws. The saws may be of either solid tooth or inserted tooth.

The trimmer.—Unlike the preceding saws, the trimmer or trim saw cuts at right angles to the grain. It is used to square the ends of timber, reduce it to standard lengths, and trim out some of the more serious defects. Trim saws, like other crosscut saws, are filed so that the top and front of alternate teeth are bevelled in opposite directions, instead of having chisel points like rip saws. They are solid-tooth saws and clearance is obtained by setting, that is, by bending the points of alternating teeth slightly outward in opposite directions.

The simplest type of trimmer is a *single swing cut-off saw.* This usually consists of a table and a pendulum-type swing cut-off saw. *Two-saw trimmers* serve as an equaliser to cut off boards to length and square ends. Larger mills have multiple trimmers. These have a battery of saws at intervals of 0.6 m or so and have a control mechanism, so that the operator can watch the boards and ensure that only the required saws are in position to cut when the board passes the cutting line.

Methods of sawing

Breaking down logs.—Two general methods are in use to "break-down" the log, namely, (1) "sawing-alive" or "sawing through an through", in which the successive cuts are made in the same plane, and (2) "sawing-around" in which the log is turned and cuts are made in two or more planes. The first method is usually more wasteful. The second method is preferable as it makes it possible to produce more high-grade timber from both sound and effective logs. This advantage is all the greater when the log has interior defects, since a large portion of the output can be secured from the outside of the log which will be reasonably free from defects. Sawing-around, however, requires more time than sawing-alive.

Plain-sawing and quarter-sawing.—Logs may be sawn into two general classes of material, namely, plain-sawn and quarter-sawn. In the former case the material is cut in a plane tangential to the growth rings, while in the latter it is cut in a plane more or less parellel to the rays and perpendicular to the growth rings. Plain-sawn timber comprises the greater part of the output of sawmills. Fig. IV-3 shows the methods of sawing plain-sawn and quarter-sawn timber.

For many purposes plain-sawn timber is preferred, but quarter-sawn timber is advantageous in certain respects. The following are the chief advantages of quarter-sawn timber over plain-sawn timber :

1. It shrinks or swells less across the width.
2. It shows less tendency to warp.
3. In many woods, it gives specialised grain or figure effects, such as silver grain, ribbon figure, fiddle-back, and parallel lines due to growth rings.
4. It offers greater resistance to abrasion and wear.
5. It does not surface check or split open so badly in seasoning and therefore, can be dried more rapidly in a kiln by giving it a more severe treatment.
6. It has a tendency to take a finish more uniformly.

The following are the advantages of plain-sawn timber :

1. It is easier and cheaper to cut at the mill, and there is less waste in cutting.
2. In some woods, it gives a more beautiful figure, such as mottle, and 'Us' and 'Vs' due to growth rings.
3. It dries more rapidly than quarter-sawn timber under the same conditions.
4. It does not collapse so easily in drying.

5. If knots are present, they appear as round knots unlike in quarter-sawn boards in which they appear as splay knots.

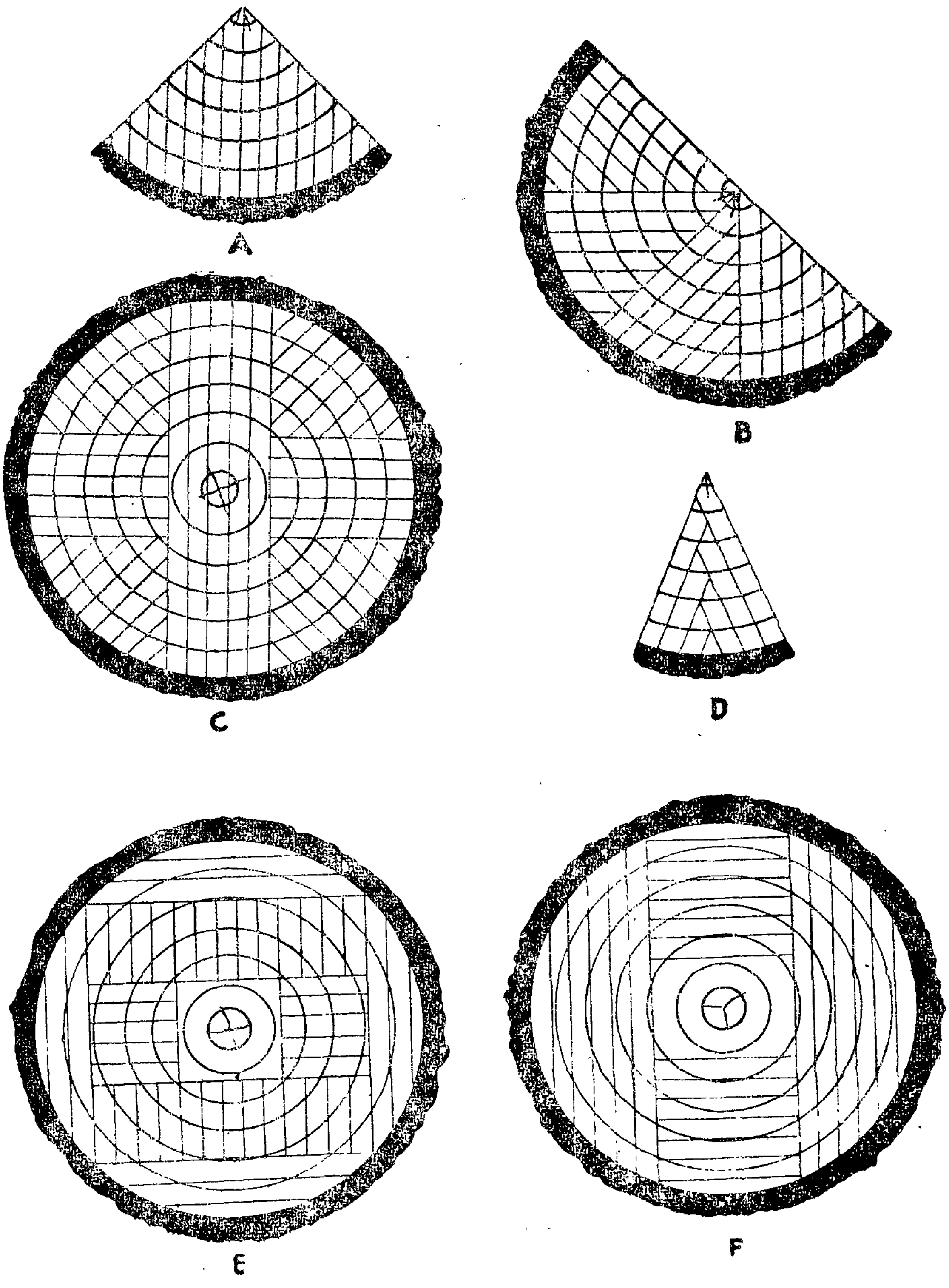


Fig. IV—3. The methods of sawing logs.

A to D represent quarter sawing. A forms the original method and probably the one which gave the name to this type of sawing. D gives the best quality timber but is not so frequently practised due to difficulties in turning the log after each cut. E involves a judicious combination of quarter sawing and plain sowing. F gives the most common method of plain sawing. E and F show boxed heart logs.

General principles of sawing

In machine sawing, considerable skill is required to convert logs, economically and with the least waste, into marketable products of good quality; no definite rules can be laid down, and a great deal depends upon the experience and judgement of the sawyer.

Each log must be studied, and the style of product required must be considered carefully before a cut is made, as a particular method of conversion may be economical for certain sizes of timber but ont

for others. The following are general instructions for obtaining the best sawn material :

(i) The best timber is usually found immediately below the bark. Therefore, off-cuts should be cut as thinly as possible and the subsequent cuts made in those thicknesses which may bring out the most favourable prices. Gradual opening of the log will disclose defects such as knots, shakes, etc.

(ii) Unless the specific object is to cut planks, the cutting should be done so as to secure cants of as large a size as possible, suitably turning the logs in the process.

(iii) With crooked logs, the bulge must be placed into the saw or away from it but never sideways to it.

(iv) Crooked logs should be sawn into planks 2.5 cm thick rather than in thicker sizes.

(v) Excessive taper, flutes and shakes cause conversion difficulties, and conversion should be judiciously done so as to reduce waste. For example, boles with extensive shakes would be better fitted for conversion into scantlings than into planks

(vi) A log with a large check should be sawn parallel to the crack : if cut across the check, either the boards produced will be narrower or the defect will appear in many of the boards.

(vii) With unfigured timbers, or for work like sleepers and scantlings where figure is not a consideration, tangential sawing is quicker and simpler, and is generally practised. Sawmills are seldom called on to convert timber so as to obtain the best figure, but if this is required the richest figure is obtained with most timbers by radial sawing.

(B) Portable Sawmills

As the name implies, portable mills are specially designed for easy transport from one site to another as occasion demands. Such a demand arises from the fact that where timber is difficult to transport in log form, or when transport cost from the forest to the market is excessive, it may be more economical to convert the logs in the forest, transporting from there only the usable timber. It naturally follows that, with continued felling and conversion, the forest compartment in which the mill is working becomes depleted of timber, and the mill has to be moved to fresh fields.

In view of the purely temporary nature of each location of the mill, the minimum of time and money should be spent on preparing the site. Each site should be so located that the average log haul from the stump site is as near a minimum as possible. To facilitate transport, the mill must be as light as possible compatible with rigidity. Machines which can be dismantled are an asset, as these eliminate heavy one-piece lifts.

It is advisable to operate only with the simplest type of machines for forest work, as no expert mechanic, with equipment at hand to rectify stoppages peculiar to complicated machinery, will be usually available.

As forest mills are normally intended only for slabbing and converting logs into sleepers, scantlings and beams, the machines required are also not of so varied a character as those used in permanent mills: one or two break-down sawing machines, a couple of circular saw-benches, a tool-room outfit, shafting, belting, pulleys, etc., are all that would be necessary for most forest mills in India.

A portable steam-engine which, in addition to driving the machines, can be used as a tractor for hauling machinery from site to site is invaluable for forest work. This engine should be capable of consuming wood refuse as fuel. Nowadays, small portable sawmills are almost always powered by interal combustion engines, burning diesel oil or petrol. Depending on the size of the mill and the extent of auxiliary equipment to be powered from the mandrel, they range in size from 20 to 100 H.P. They are popular because they can be moved easily, set up quickly, and put into operation without difficulty.

With regard to the choice of machinery much will depend upon the class of work to be done and the output required. Rack benches, band saws, frame saws, crosscut saws, saw-benches and tree-fellers, all of a portable nature, are available; and if properly run any of these machines will satisfy the requirements of an average forest mill.

Good foundations are essential for most high-speed woodworking machines, and it is advisable, wherever possible, to bolt machinery down to a cement concrete base. This is not really an expensive operation, and as it will eliminate vibration to a great extent, the machine output will be improved.

Where one machine only is employed, it is quite possible to drive this machine direct from the engine, but when several machines are to be driven off one engine, main shafting and possibly countershafting, must be introduced. Fig. IV-4 depicts an idea for a semi-portable mill with a rack circular saw-bench for breaking down logs. There is, however, nothing hard and fast about mill designs, and each mill must be laid out to suit the requirements of the project in hand.

Wood Workshops

Wood workshops contain the various classes of machinery and tools necessary for the conversion of timber from the rough log to the finished product. The machinery and tools differ from those for metal working because the speeds of cutting the material are relatively much greater and the methods of holding or feeding it are usually quite different. The different types of sawing machinery—head saws, re-saws,

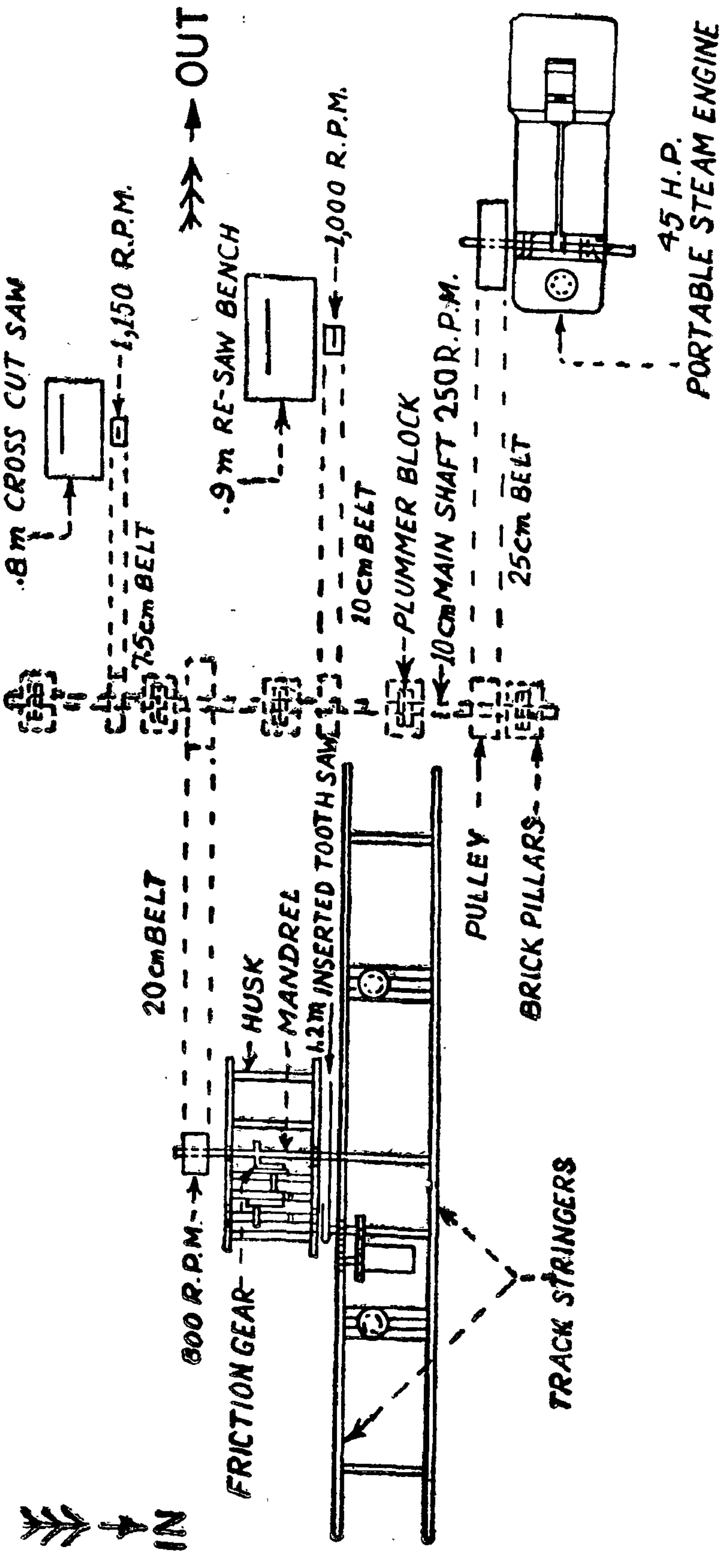


Fig. IV-4. Lay-out for a semi-portable circular sawmill.

edgers and trimmers—have already been discussed. Several other machines and tools find a place in a general purpose-machine shop. Some of these are intended to work directly on wood, while others form the equipment of the tool shop and are intended to keep all tools in working order. The more important ones of these machinery and tools are briefly dealt with below.

Machines for woodworking

These comprise small ripping and crosscut circular saw-benches, surfacing machines or combined over-and-under planers, band scroll saws, thicknessing machines, sandpapering machines, power-feed moulding and matching machines, spindle irregular-moulding machines, tenoning machines, chain mortising machines and boring machines.

General purpose circular saws.—These are used for several types of cutting, such as ripping, crosscutting, beveling, mitring, rebating, grooving, etc. The circular saw-bench is made in various styles with a fence which guides the wood. The most complete types are the dimension saws which have a complete system of adjustments to angles and positions, with graduated scales for reading the extent of cutting of all sorts required.

Surfacing machine.—This is invaluable in a general mill. It is used for edging, facing, taking out 'wind', chamfering, rebating and trueing up. These machines run at high speeds, and as a result the frames have to be of solid construction and mounted on a good heavy base to absorb vibration. To adjust for depth of cut the tables, both in front and behind the cutter block, are capable of independent vertical adjustment.

Thicknessing machines.—There are several modifications of thicknessing machines in the market, and the choosing of such machines, or for that matter any machinery, is a matter of personal requirements. It is, however, a good policy to avoid machines having too many complications and intricate parts. The function of the thicknessing machine is to bring timber down to a given thickness after it has been faced and edged on a surfacing machine. The machine is fitted with top and bottom cutter blocks, each carrying two or more knives, and the timber is fed to the knives by means of fluted rollers. Pressure bars are provided to hold the timber down on to the table during the cutting operation.

Over-and-under planer.—This machine is a combination of a surfacing machine and thicknessing machine. It does all the work usually performed on a surfacing machine, and has, in addition, an independent rising and falling table, placed below the cutter block, for planing to thickness.

Sandpapering machines.—These finish wood of different shapes, some against a flat disc, others on an endless band. The drum machines are the largest kinds for expensive output and have three drums for successive action. The first has coarse paper, the second finer and the third finer still with a soft cushion beneath to produce a high finish. A brush cleans off the dust.

Band scroll sawing machines.—A serviceable band scroll saw for light work, such as cutting irregular curved lines, is one with saw pulleys of 60 to 75 cm diameter. A small band or ribbon of steel having teeth along one edge is strained over the pulleys, and rotates round them when the machine is running.

Power-feed matching and moulding machines.—These are usually of a complicated character carrying several horizontal and vertical cutter heads which can be fitted with shaped cutters for introducing mouldings, tongues and grooves on prepared stock. The timber is fed to the cutters by means of rollers, and the machine is so constructed that all four sides of a piece of timber can be dealt with at one operation,

Spindle irregular-moulding machines.—These are intended for cutting mouldings in straight and irregular shaped timber. By means of special apparatus, dovetailing and small tenoning work can be neatly executed on such machines. Balanced cutters, of the shape required for the work in hand, are mounted in a vertical cutter head which revolves at high speed, and the stock to be moulded is fed to the cutters by hand.

Tenoning machines.—There are various forms of tenoning machines, and selection must depend entirely on the size and style of work to be done. In general, the machines are usally fitted with cutter spindles capable of cutting tenons with shoulders of different lengths. The cutters are arranged to give a shear cut and can usually produce single tenons, double tenons, bottom scribing, top scribing or both.

Mortising machines.—These operate either vertically or horizontally and like most other wood-work machines there are various types, such as hallow mortisers, chain-cutter mortisers, combined chain and hollow chisel mortisers, and combined bit and hollow mortisers.

Boring machines.—For light boring work, any of the following types of boring machines are equally good : pillar, wall, vertical or horizontal boring machines. Preference might be given to the machine which provides for the bit being brought to its work by means of a lever or handwheel, rather than the type of machine which requires that the timber be fed by hand to and from the bit.

Tool shop

As the output of a sawmill and machine shop depends in a very great measure on the condition of the saws, planing knives, cutters and other machine tools, most up-to-date mills maintain well-equipped fitting shop for the purpose of keeping all tools in perfect order. The mean employed in these shops must thoroughly understand their work if success is to be attained.

A well-lit room should, for preference, be set apart for the fitting shop. The requirements of this room include grinding machines for shaping moulding cutters, saw-sharpening machines suitable for sharpening and gulleting the saws, band saw filing machines, band saw setting machines, brazing clamps and brazing material, heating appliances for brazing work, band saw stretching rolls, automatic knife-grinding machines grindstones, grinding apparatus for chain mortise cutters, cutter balances, a forge, various grades of emery wheels and files, steel straight-edges of various lengths, swage sharpeners, side dressers, saw-sets of various sizes, set gauges, an anvial and hammers for tensioning, high-speed tool steel for cutter making and material for saw packing.

As is the case with woodworking machines, there are many types and modifications of the machines used in the tool room, and the following brief descriptions will give an idea of the variety of machines usually employed in a tool shop.

Grinding machines for moulding cutters.—These machines are designed for shaping and grinding cutters of irregular patterns. They are usually fitted with several stones of various grades and thicknesses in order to enable the operator to obtain any desired shape. Tools rests and a water cistern fitted with water-taps are usually provided with the machine.

Saw-sharpening machines.—There are several types of saw-sharpening machines in the market, some of which are automatic in action. These machines are fitted with emery stones and have refinements for tilting the stone to obtain any desired grinding angle. The saw teeth are automatically fed to the emery stone, and when once 'set up' the machine will complete the work it is set to do with very little further attention.

Hand-operated models are usually constructed with a balanced swing frame in which the emery wheel is carried. The stone can be tilted to suit the shape of the saw teeth and is fed to its work by hand.

Automatic knife-grinding machine.—With this machine, the knives to be ground are bolted to a carrier having a canting adjustment, and fitted to a traversing table which brings the knife in contact with an emery stone along its entire length. The headstock and emery wheel may be mounted, and the stone fed towards the knife by means of a balance weight, or inversely the stone may be fixed and the knife brought to the stone by the carrier to which it is bolted.

Band saw filing and setting machines (small saws).—Compared with hand filing and setting of small band saws, an automtic machine saves considerable time and will deal with up to about 80 teeth per minute. The machine is so designed that the teeth are fed up to a taper file which does the sharpening whilst an automatic setting tool introduces the set. Several modifications of this machine are available.

Band saw brazing clamp (small saws).—This is simple little apparatus used for exerting pressure at the joint during the process of brazing the ends of a band saw. The ends of the saw to be brazed together are bevelled to form a scarf joint. The joint is cleaned and a flux applied, together with a brazing agent, which is brought to melting point when the clamp is brought into operation on the joint.

Cutter balance.—To produce good results and to reduce or avoid chatter, the cutters or knives on any single cutter block should be perfectly balanced, and, in planning machines, must have their weight

evenly distributed along their length. The cutter balance is designed to enable the cutter grinder to detect errors in the balance of cutters and knives.

Emery wheels.—These wheels are made in a variety of shapes and grades for different types of grinding work. Good quality wheels free from flaws are essential and they should not be driven at a periphery speed in excess of that laid down by the maker. Bad quality emery wheels may 'fly' and cause accidents, and too much care cannot be exercised when running emery wheels even of the best quality. Accidents are liable to occur through work being caught up between the emery wheel and the rest, through excessive pressure the presence of flaws or improper mounting.

Some Sawing-Machine Troubles and How to Avoid Them

With woodworking machinery it is almost impossible to foresee all circumstances which may cause bad results in output and quality. Most kinds of machinery have a tendency to get out of order, or to give poor returns, and woodworking machinery are certainly no exception.

To keep machines in proper order and to obtain the best possible results, the operators must not only know their machines, but must be prepared to meet any unexpected contingency which may arise and, if necessary, to introduce original improvisations for overcoming difficulties.

Trouble with sawing-machines may be due to one or more of the following causes: (1) uneven packing of the saw, (2) uneven sharpening and setting, (3) uneven tension, (4) tension too slack or too tight at the centre, (5) the pitch, packing, hook or gulleting not being suitable for the work in hand, (6) bad alignment of the carriage, (7) faulty bearings, (8) poor lubrication, bad quality of lubricant or the presence of grit, (9) imperfections in saw collars, (10) saw not balanced, (11) inattention to the correct hanging of saws, (12) belt slip or too tight belts.

Uneven packing.—Uneven or insufficient packing is a common reason for saws not running true. Packing should be done when the saw is in the bench, and must be so fitted that the saw runs steadily and slightly warmer at the centre than at the rim. Saw-benches are generally supplied already fitted with packing receptacles. These take the form of two pieces of wood which are screwed or bolted to the underside of the finger plate on the one side and below the saw table on the other side of the saw. Both pieces of wood are rebated on the top edge, which allows for the insertion of hemp or other packing, which should be evenly bedded and without excessive pressure on both sides, and from the centre to the front of the saw. For the purpose of steadying and guiding the saw, it is a good practice to fasten two small pieces of felt or leather to the wooden packing pieces at the back, and near the rim of the saw. Many sawyers have sets of packing sticks which they keep with them for use with differently gauged saws. These consist of thin pieces of wood of a length equal to about half the diameter of the saw. The sticks are lapped from end to end with rope yarn, and when placed in position in the packing spaces they should exert an even pressure on both sides of the front half of the saw plate, from the teeth to the eye, and should not protrude above the level of the table top. Saws should not be packed too tightly and lumps or knots in the rope yarn wrapping should be avoided. Lumps or any kind of unevenness in packing always causes uneven friction at the point of contact on the saw plate, which results in the saw running out of line.

If, after being properly packed, the saw continues to run out of truth, the teeth must be stoned until the saw is perfectly round and the stone touches every tooth as the saw revolves. Then the teeth can be resharpened and set, and carefully repacked. Should this treatment not give the desired results, the saw should be sent to the tool room for examination with regard to tension.

Adjustment of saw fence.—Speed of output within certain limits is, of course, one of the first considarations of the sawmiller. In attaining this, care must be taken to avoid overfeeding a saw beyond the limit compatible with good quality of cutting. This, together with an improperly adjusted saw fence, may cause a saw to run untrue. In ordinary workshop practice, there appears to be very little reason for having a saw fence extended to more than 7 to 10 cm beyond the teeth at the front, as otherwise the wood will seize the saw, owing to its not having sufficient room to open out as it leaves the saw. In cutting large logs, or springy timber which closes in on the saw plate during conversion, wooden wedges should be used in the kerf at the take-off end of the bench to give extra clearance to the saw, and so prevent jamming and buckling.

Maintenance of bearings.—All bearings should be kept free from grit and dirt, and only a good quality lubricant should be used on them. They should not be screwed up too tight but tight enough to prevent play. End play on spindles must not be tolerated. Should a bearing continue to run hot after ordinary precautions have been taken, the best remedy is to take it down and have it trued up. As a rule, any heat which is generated at the bearings of a saw spindle will be transmitted to the saw and give trouble.

Saw doctoring.—The necessity for keeping saws in perfect condition cannot be too strongly emphasized, as this is one of the main secrets of successful conversion. A brief outline of the methods employed in saw sharpening, levelling and tensioning may be found useful and is given below.

There are many forms of saw teeth (Fig. IV-5), and it is common knowledge that practical millmen have their own ideas as to what constitutes the best type of teeth for any particular timber or class of work. In general, it may be said that teeth intended for ripping timber have a forward rake or hook, whilst those for cross-cutting are not given any hook.

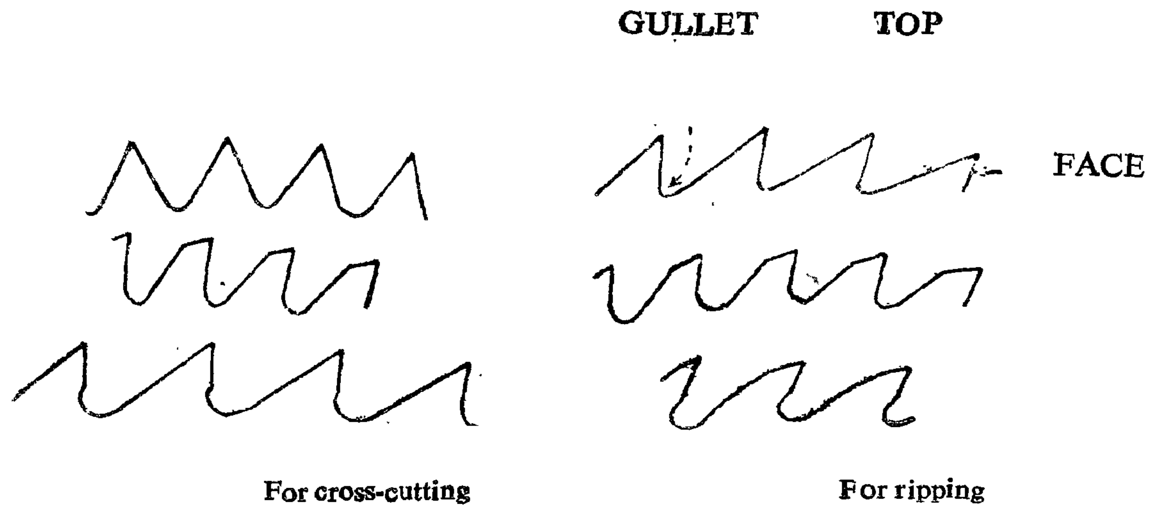


Fig. IV—5. Typical circular saw teeth.

Whatever type or shape of tooth is used, the teeth must be kept sharp and, in the case of rip saws, properly set. The body of the saw must be free from lumps and properly tensioned, and the saw must run constant at the speed for which it is tensioned.

Every tooth in a circular saw, except novelty saws, must be of the same shape and height, and whichever style of set is employed that set must be uniform.

It is not good practice to 'top' a saw, i.e., to sharpen it by filing the tops of the teeth whilst the saw is hung on the mandrel in its bench. This practice will reduce the gullets to an extent sufficient to give poor conversion return both in output and quality, and may do considerable damage to the saw plate.

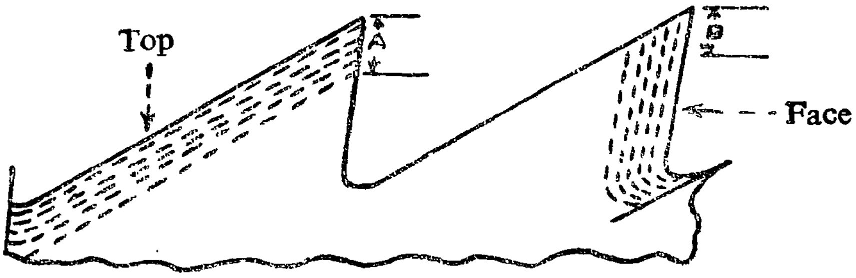
The function of the gullet is to collect and carry the sawdust out of the cut. The gullets of each saw should be sunk to one common depth, this depth being governed by the feed speed and kind of timber being converted; timbers of a soft variety requiring bigger gullets than hardwoods.

It will thus be seen that by 'topping' teeth the size of the gullet is reduced and that the gullet should be deepened to the same extent that teeth are reduced at each sharpening.

To do this, the saw should be removed from the saw-bench and mounted on a saw-sharpening machine fitted with an emery disc adaptable to gulleting. The machine can then be set to bring all gullets to the same depth.

By applying the emery wheel to the face of the teeth, the same machine will do the sharpening, a light touch of a file being given to finish off.

Fig. IV-6 shows how sharpening saw teeth by face filing is more economical than top grinding.



Sharpening on top and face

Swage-set Spring-set

Fig. IV—6. Sharpening and setting of saws.

Saws, can, of course, be sharpened and gulleted by hand filing, but this is a slow process, and the results are not usually so uniform as those obtained by machine sharpening. It is usual, before commencing to sharpen a saw, to bring all teeth to a common height.

Care must be taken to avoid too much pressure when using emery wheels, as this will result in bluing or burning the metal.

Except that with frame saws and band saws teeth must be kept in a straight line, the sharpening procedure for these saws is more or less the same as for circular saws.

Set is given to the teeth of saws to provide clearance for the saw as it passes through the cut, and is so arranged that the kerf produced is wider than the thickness of the saw plate, which prevents the timber binding on the body of the saw.

There are, in common use, two forms of set for saw teeth, spring-set and swage-set. With the former, the cutting point of each alternate tooth is bent over to the right and left, and with the latter the cutting points are splayed to a width in excess of the thickness of the saw plate.

When applying spring-set, either one-handled or two-handled saw-sets are used, as well as a saw-set gauge.

Saw-sets are fitted with slots to accommodate various gauges of saws. The required slot is passed over the teeth to be set, and the teeth are then levered over the right or left as the case may be to the desired extent. A check is made, by means of the saw-set gauge, to make sure that all teeth have received the same amount of set.

There are several ways of introducing swage-set to saw teeth, and nowadays there are mechanical appliances for this purpose which require little skill to handle and give good results. These are the 'swage tool' and 'side dresser'. Teeth for swaging must be of a suitable shape, and the point must be of an acute angle to swage out easily, but must at the same time be strong enough to stand cutting strains. Bevel is not applied to this form of tooth, which should be made sqaure across the points, as otherwise the saw will probably 'run' in the cut. Swaging is usually a little overdone to allow for side dressing, and the corners of the teeth are trimmed to make them uniform. Provided that swaging has been properly done, a saw can be resharpened a few times before it requires re-setting. Compared with a rip saw, a crosscut saw requires very little set.

Saw teeth should have the right set and hook for the timber being cut, softwood as a rule requiring more set than hard wood. A swaged saw, although probably requiring more power to drive, will do faster cutting than a spring-set saw. Teeth which are too high at thier backs may cause a saw to seize and heat at the rim. In addition, the formation of square corners at the base of saw teeth may cause a saw plate to crack, and for this reason, and also to give greater dust space, the gullets should be kept round.

The quicker the timber is fed to the saw, the lower the back of the teeth should be. The number of teeth a saw should have is more or less governed by the gauge of the saw, the kind of timber to be sawn (usually more for hardwoods than for softwoods), and also by the speed and feed at which the machine is being worked.

Good running of saw.—If a saw heats at the rim, it is probably due to either one or more of the following causes : (1) saw not open enough at the body, (2) insufficient throat room for dust, (3) backs of teeth too high, (4) gum and resin on the teeth, (5) guide pins too close, and (6) insufficient set.

A saw may become heated at its centre on account of : (1) the mandrel running too warm, (2) insufficient set, (3) saw too open at the centre, (4) speed too low to expand the rim, and (5) saw lined too much out of the log. A saw should run at the same speed when cutting as when 'idling', i.e., running free. The holes in a saw should be an easy fit on the steady pins and mandrel, and end play should be avoided.

To obtain a good running saw, the collars and stem of the mandrel must be true and well fitted, as any irregularities in the collars will be multiplied many times at the rim of the saw. Collars should be concave or recessed from the centre up to about 2.5 cm from the rim, which should have a perfect bearing on the saw plate. The stem of the mandrel being true, the hole or eye of the saw should be just large enough to allow the saw to slip easily up to the fast collar and steady pin. Before hanging a large saw, it is as well to test it with a straight-edge and, if it is true, the saw can be placed on the mandrel and the collars securely tightened. Another test with a straight-edge should then be made to ascertain if the saw has been thrown out of shape: if it is so, the fault will no doubt be in the collars, and damage to the saw may ensue if it is allowed to run in this state. Many difficulties due to the collars may be overcome by the introduction of paper washers. If the saw is 'dished' on the side nearest to the log when cutting, a ring of paper of the size of the collar, and about 2 centimetres wide, may be cut. This paper ring should be moistened with oil and can then be placed on the loose collar. A smaller ring of paper of the same width should be made to fit the mandrel and should be placed against the fast collar. Should one thickness of paper not be sufficient, further rings can be added until the saw becomes true when tighthened up between the collars. A saw which is 'crowning' on the log side should be treated in a reverse manner to a 'dished' saw, the larger paper rings being placed against the fast collar and the smaller ones next to the loose collar.

Uniformity in speed of saws is an important factor in producing good output, and in securing this the following table of speed should be followed :

TABLE IV—2

Circular Saws

Diameter and corresponding revolutions

Diameter of saw (cm)	Revolutions per minute	Diameter of saw (cm)	Revolutions per minute	Diameter of saw (cm)	Revolutions per minute	Diameter of saw (cm)	Revolutions per minute
45.7	2,000	71.1	1,285	96.5	950	121.9	750
50.8	1,800	76.2	1,200	101.6	900	127.0	725
55.9	1,636	81.2	1,120	106.7	870	132.1	700
61.0	1,500	86.4	1,050	111.8	840	137.1	675
66.0	1,384	91.4	1,000	116.8	800	142.2	650

The following are the rules for calculating the speeds of pulleys and saws :

(1) If the diameter of driving and driven pulleys and the speed of the driver are given, the speed of the driven pulley is obtained by multiplying the diameter of the driver by its number of revolutions and dividing the product by the diameter of the driven pulley.

(2) If the diameter and revolutions of the driven pulley are given, then the diameter of the driver is obtained by multiplying the number of revolutions of the driven pulley by its diameter and dividing the product by the number of revolutions of the driving shaft.

The levelling and tensioning of saws is a difficult craft, the art of which is only acquired after considerable experience coupled with judgement and skill. In other words, it is a specialist's work, and unless a mill can afford to maintain a saw-doctor it is better not to attempt tensioning but, instead, to send such saws as required attention to the makers or to some other mill which has a saw-doctor.

When a circular saw is in tension it should, when raised from the anvil, fall away between the collar and the teeth so that when a straight-edge is placed across the plate from the collar to the teeth a curve should be observed. Band reciprocating saws should show a curve between the teeth and the back of the blade.

REFERENCES

1. Brown, N. C.	1937.	Timber Products and Industries; John Wiley & Sons, Inc., New York.
2. Brown, N. C. & Bethel, J. S.	1958	Lumber, The stages of manufacture from sawmill to consumer; John Wiley & Sons, Inc., New York.
3. Bryant, R. C.	1922	Lumber, its manufacture and distribution; John Wiley & Sons, Inc., New York.
4. Eyres, H. T.	1950	Introducing Wood; Pitman, London.
5. Panshin, A. J. & Harrar, J.S. Bethel & Baker, W. J.	1962	Forest products, their sources, production and utilization, 2nd Edition; Mc Graw-Hill Book Company, New York.
6. Trotter, H.	1940	Manual of Indian Forest Utilizatiion; Oxford University Press, London.
7. Varossieau, W. W.	1954	Forest Products Research and Industries in the United States; J. M. Meulenhoff Amsterdam.

CHAPTER V
GRADING

Introduction

Grading has been known to exist ever since timber came into use for some purpose or the other. Our early ancestor found, by trial and error, that a knot in the handle of his club was likely to let him down at the critical moment and that he must choose his club with a handle which is straight-grained and free from knots and other defects.

Intelligent choice of timber for specific purposes is what is generally understood as "Grading". The first set of written "grading rules" were reported in Sweden as early as in 1764 for Swedish pine. Gradually, more and more rules came into existence for different species or groups of species in other countries also. Maximum development in this field has been noted in the U. S. A. and Canada, where the species for different uses have been classified according to agreements between suppliers and consumers.

In India, interest in grading was first shown by the Forest Research Institute, Dehra Dun, and by the Forest Departments of some States, e.g., Madras, Mysore and Bombay, which had developed more and more of departmental extraction and conversion. Based on physical and mechanical properties of timbers tested up to 1922, L. N. Seaman (1924) suggested some tentative grading rules for stiuctural timbers, and these were modified first in 1926 by L. N. Seaman and C. R. Ranganathan and again in 1934 by L. N. Seaman. S. H. Howarad (1927) incorporated the above grading rules for Indian structural timbers and also a separate grading specification for sleepers in his Forest Pocket Book. Seaman and Limaye (1935) prepared the "Rules for the grading of Teak Squares", and this eventually served as a basis of classification for the international grading of teak squares by the Asia Pacific Forestry Commission, F.A.O., (1958) and, subsequently, for the modified Indian Standards grading rules for teak squares (I. S. : 3731-1966). Between 1957 and 1967, A. C. Sekhar published several papers on different aspects of grading.

At present most of the forests in India are state-owned, and forest departments have evolved their grades for important species where departmental extraction and sale are in vogue. Several large-scale consumers of timber are also Government agencies, like the Defence and the Railways, who insist upon their own specifications for logs, converted material, etc., on the plea that their requirements are of a special nature. These specifications undergo changes now and then, with the mutual agreement of the consumers and the suppliers, depending upon the availability of the material. However, the impact of these changes on the timber trade, and timber economy of the country as a whole, is overlooked sometimes. The private timber trade existing in various regions of the country practise, within their own limited spheres, varying systems of classifying timbers for general purposes. Compared to other countries there is practically little export of timber, with the result that no Indian grading specifications are at present used in internatinoal markets. In recent years the Indian Standards Institution has attempted to draw, on a national basis, several grading specifications for coniferous and non-coniferous material for some specific purposes. Some of the important specifications on grading and rational use of timber are given below :

1. IS : 190-1950 — Coniferous sawn timers intended for further conversion.
2. IS : 399-1963 — Classification of commercial timbers and their zonal distribution.
3. IS : 883-1966 — Code of practice for use of structural timber in building (material, grading and design).
4. IS : 1326-1958 — Non-coniferous sawn timber intended for further conversion.
5. IS : 1329-1958 — Air-craft timber for further conversion.
6. IS : 1331-1966 — Cut sizes of timber.

7. IS : 1629-1960 — Rules for grading of cut sizes of timber.
8. IS : 2179-1962 — Timber for lorry bodies.
9. IS : 2184-1962 — Tables for volumes of round timber logs.
10. IS : 2377-1967 — Tables for volumes of cut sizes of timber.
11. IS : 3364-1965 — Methods of measurement and evaluation of defects in timber.
12. IS : 3731-1966 — Grading rules for teak squares.

Besides the above, there are specifications for specific end uses like Ballies, Wood Poles, etc., which classify them in different classes and grades.

The Central and State Public Works Departments, Military Engineering Service, etc., have their own specifications, and these are followed in their respective limited circles.

In spite of available data on several species (Limaye : 1944, 1954), this country has been using only teak and a few popular species of timber for almost all needs. However, during the last fifteen years, several secondary species and substitutes of popular timbers have actually come into use for various purposes, such as vehicle bodies, agricultural implements, packing-cases, sports goods, jute and textile mill accessories, etc. Alternative species have also been recommended for doors and windows and various types of construction (Rehman, Purushotham and Sekhar : 1956). But owing to the acute shortage of timber, and the lack of proper quality specifications for the species employed for different purposes, timber is not able to play its rightful role in many of the industries. Stan dardisation and grading of timber and timber products are much needed developments that have attracted considerable a ttention in recent years.

Scope and purpose of grading

Being a biological product, timber exhibits considerable variability in its quality and, therefore, has a tough competition from industrial and engineering products which are usually manufactured to desired specifications. In order to minimise such variability, introduce greater confidence in its use and effect a rational economy, timber requires to be suitably "graded" before actual use. Thus the framing of grading rules for the classification of timber into various classes on the basis of species, uses, sizes, defects and other physical features, consistent with the economic aspects involved, becomes an important procedure ; these rules indicate confidence limits. Grading rules presuppose a clear understanding of the nature of the above factors and their influence on utilization. The term "grading" has been used to include a very wide field of grouping and classification to distinguish not only individual pieces of timber of a particular species but also groups or sets of species according to their properties or products made out of them. However, for practical purposes, "grading rules" have come to be recognised as those which provide general guidance and basis for drawing individual grading specifications for classifying material of a particular species, or groups of species, for differentiation of quality and consequent price structure. "Grading rules" are generally issued by recognised organisations, like the Lumber Manufacturers Association of the U. S. A., etc. Such organisations also assume the role of an authority to issue certificates of grading. These rules also include provisions for code of inspections, rules for selection and marking, storing and re-inspection. They also contain standard forms of certificates and other clauses covering any legal issues arising out of grading. Thus "grading rules" have generally come to be associated with organisations and institutions, and their specifications are restricted to individual species, or groups of species, or specific end-uses. However, where organised institutions do not exist for grading, some provisions of such "grading rules" are also embodied in specifications prepared by different organisations for different types of material.

The essentials of any grading system for preparing individual specifications for species or end-uses are the following :

(1) Clauses to regulate the quality in accordance with demand and supply.

(2) Clear definitions of the grades or classes, both qualitatively and quantitatively, keeping in view their impact or price structure.

(3) Identifications and evaluation of factors which influence the quality and utilization of the material,

The specifications also contain relevant clauses for mode of inspection, storage, re-inspection and safeguards against any legal matters arising over interpretation, or inspection and classification, and necessary proformas for keeping records of inspection and certificates, etc.

Present systems of grading and practices in measurements and calculations in India

It is well known that timber is classified very broadly, according to its botanical origin, into 'hardwood' and 'softwood' classes, i.e., the broad-leaved timbers and the conifers. Further classifications, according to (i) species, (ii) size and shape and (iii) resence of defects, are broadly divided into two categories : (1) structural or stress grading, and (2) normal commercial garding, which may conveniently be otherwise called 'utility grading'. Discussion on the former is dealt with separately under later paragraphs. With regard to the latter, the various grading practices now current in India can be broadly classified as follows :

(A) *Grade classification based purely, and sometimes arbitrarily, on (a) dimensions and (b) general appearance.*—The dimensions of lengths and girths for logs, or lengths, widths and thicknesses of converted material, are measured according to specified methods. This system is prevalent in Kerala and Mysore. Under these classifications, teak is placed in four grades with two sub-classes in each grade. In the case of other hardwoods, there are similarly four grades in Mysore (Coorg) but the dimensions are fixed separately for each of the species. In Kerala, there seem to be only two grades of hardwoods.

(B) *Grade classification based on the best ultimate use of logs or converted material.*—Such a system is mostly prevalent in Andhra Pradesh and some parts of Madras, and seems to be one of the quickest systems of grading and marking. The logs are classified into grades on the best use possible as for beams, planks, scantlings, etc., and each grade is further divided into 'A', 'B' and 'C' classes to indicate occurrence of defects. Only two lengths are recognised : 'long' (i.e. 15′ or 5 m and above) and 'short' (i.e. under 15′ or 5 m). Each log is thus quickly stamped with the first letter of the grade classification, the sub-class, and 'L' or 'S' for 'Long' and 'Short'. For example, BAL and PBS indicate, respectively, "Beam, A-Class, Long" and "Planks, B-Class, Short". Sometimes another letter is also added to indicate the species, e. g., 'T' for teak. For guidance as to the best use, indications of dimensional requirements (e.g. girth for logs) are given in the specifications.

(C) *Grade classification based purely on defects and estimates of outturn.*—Under this, there are four classes of tea in some areas of Madhya Pradesh and only two classes in other areas of the same State.

(D) *Grade classification based purely on evaluation of "units of defects" and fixing the number of units permissible for a standard volume in each grade.*—Such practices are common in the Bombay region ; sometimes an estimated outturn is also indicated in each grade. In general, three grades are distinguished for various categories of logs and sawn timber. Sizes and other dimensions are also fixed in a few cases, separately for different species and different depots in the same State. This system is being increasingly adopted in the specifications of Indian Standards Institution, and in international grading specifications. This system has a distinct advantage of evaluating cumulative effect of defects in a particular grade.

Besides such classifications, there is a system in Madhya Pradesh of grading of sal into three grades, according to its fitness for disposal as follows :

(a) fitness for sale at a rail-head depot ;

(b) fitness for conversion in the semi-permanent sawmills of the forests; and

(c) fitness for being disposed of in a forest depot only, such fitness being decided by a gazetted officer of the forest department.

In some regions like Assam and Bengal, there are no separate grading rules of the forest department, but logs are generally supplied according to the requirements and specifications of the individual purchasers.

At present there are no uniform practices common throughout the country for measurements of dimentions of logs and converted material, or for volume conversions. Very often these are agreed

upon between the buyers and sellers directly, and are provided in the purchase contracts or local speci fications. Some recent trends indicate the likely provision of specific clauses in the Indian Standards on these subjects, and it is hoped that, by a continuous usage of such all-India Standards by the general trade, some sort of uniform procedures will be obtained throughout the country. From a general survey the various existing practices may be summarised as follows :

(a) *Lengths of logs* : Lengths are measured mostly by tape and rarely by foot-rule. Drag holes, and sometimes the end defects, are excluded in its measurement. Lengths are recommended to be measured in metres and rounded off to the nearest lower 5 cm in most of the Indian Standards. When the ends are not cut at right angles, the general practice is to measure up to the point that will give a full flat cut.

(b) *Girths and diameters* : In case of standing trees, calipers are used for measurement of diameters and tape is used for measurement of girths. This is usually done at breast-height, which is $4\frac{1}{2}'$ or $1\frac{1}{2}$ meters from the ground. But in the case of felled logs these are measured mostly by tape, and rarely by foot-rule. Measurement of diameter is not as common as girth measurement is logs. When diameters are at all measured the smaller ends of logs are taken. The average of the greatest and smallest of that end is considered as sufficient for grading, and not necessarily the perpendicular diameters as in some countries. Girth is generally measured at mid-length of the log, to the nearest cm, but sometimes it is measured at the two ends and the average is taken for volume calculations. Where grading is done by diameter classification, diameters are sometimes roughly estimated as one third of the girth.

(c) *Bark allowances* : Measurements are normally made under the bark. Where, as in standing trees, measurement is made over bark, the bark allowance depends upon the species and the locality concerned.

(d) *Converted timber* : The dimensions of the converted timber are measured either by tape or scale. In measuring the length, fractions of a metre are generally rounded off to the nearest lower 5 cm. The widths and thicknesses are measured generally at the narrowest places in cm or mm, and rounded off to the nearest cm or mm as per the recommendations in the various Indian Standards. The 'faces' of any piece of converted timber are taken as the four longitudinal surfaces, sometimes further designated as *wide faces* or *narrow faces*. In a material which is used for bending, the wide faces are referred to as vertical faces and the narrow faces as horizontal faces, unless otherwise indicated. The 'edges' of any piece are understood to be the narrow faces and the 'sides' refer to wide faces. However, when the 'edge of a face' is referred to, as in structural grading, it is meant to be the intersection of two adjacent faces.

(e) *Volume calculations* : Volumes are generally obtained by reference to prepared tables. In the case of logs, these are mostly based on the quarter-girth formula, i.e. Volume = $(\text{Quarter girth})^2 \times \text{length}$. In some parts of the country, the logs are initially sorted into various girth-classes and the average girth of the class is used with the total length of all the logs in that class for getting the total volume of the logs of that class. But in most of the depots they keep an account of each log separately. Deductions in the volume, for such defects as will detract from the outturn on conversion, are sometimes made only by agreement, and no standard practice exists at present for the same.

In measuring defects, normally scales are employed to measure the diameters of knots, widths, lengths and depths of checks, shakes and splits. However, sometimes probing wires and feeler gauges are also employed. As most of the grades provide round numbers for limiting the sizes of defects, very high accuracy is not attempted. Detailed methods for measuring and evaluating defects are dealt with separately later on.

It is well known that the dimensions of timber change with moisture content below its "fibre-saturation-point". For this reason, a specific moisture content is also indicated in grading specifications which prescribe limiting sizes. In conformity with certain international standards, the Indian Standard IS : 1331 also prescribes 20 % moisture content or storing cut sizes of timber. In other specifications a moisture content of 12 %, or sometimes 15 %, is prescribed for convenience. Hence, when the moisture content

is not the same as prescribed in the specification, say m, the permitted dimension at the observed moisture content, say m', is calculated by the formula

$$d_{m'}=d_m\left[1-\frac{K(m-m')}{100}\right]$$

where $d_{m'}$ = required dimension at the moisture content m';

d_m = given dimension at the moisture content m;

m = given standard moisture content;

m' = observed moisture content of the material;

and K = a factor, representing shrinkage per unit moisture content on the basis of dimensions at the standard moisture content m.

In the above formula, K is dependent on the fibre-saturation-point and also the normal shrinkage values of the species in question, usually reported under standard strength data. There are four such shrinkage values given in the standard data (green to oven-dry, and green to air-dry, in the case of radial and tangential planes separately) which have been worked out for various species at the Forest Research Institute, Dehra Dun (Sekhar & Sharma : 1967). It has also been found that a relation between the average K of the above four values and the specific gravity ρ exists in the formula $K=0.41\ \rho$. But considering a large number of species with varying fibre-saturation points, shrinkage values and specific gravity, it has been recommended that a K value of 0.2 can be used for all species of specific gravity below 0.6, and a value of 0.3 can be used for all species of specific gravity above 0.6. In cases where specific gravity is not known, but the corresponding dimensional stability factor is known in terms of suitability indices of retention of shape, K value of 0.3 is used for those below 60 and a value of 0.2 is used for species above 60. Where both the specific gravity and dimensional stability are not known, a K value of 0.25 is recommended as the nearest approximation.

Measurement and evaluation of some defects for the purpose of grading

As stated earlier, most important factors which influence utilization are the defects that are present in the material to be graded. In specifications the limitation of the permitted defects distinguishes material of one grade from another. More recently the cumulative effects of defects have engaged attention, and this trend has indicated the need for standardization of methods of measuring defects and the establishment of a system of quantitative evaluation of common defects in terms of "units of defects", giving due consideration to the location and distribution of the same. However, it should be recognised that even though an approximate relationship may exist between the grade of a material on the one hand and, on the other, the prercentage of the utility value as indicated by the defect unit and its consequent price structure, defects cannot be quantitatively evaluated by any rigid mathematical calculations, which can serve only as a general index, for obtaining the cumulative value. As such, the use of such quantitative systems is subject to the limitations of the tolerances and accuracies as presumed in the measurement of the defects in any specification.

The most common defects and their measurement and evaluation are described below briefly. (For a fuller understanding a reference may be made to Chapter XIII "Defects in Timber" and to Indian Standard IS : 3364-1965 for methods of measurement and evaluation of defects in timber). The "unit of defect" is defined as a quantitative representation of the approximate degrade of the utilizable material for each defect. As mentioned above, the sum of the units of various defects is expected to give a total estimate of the entire degrade due to all defects presents simultaneously in the material under consideration.

(i) *Check*.—A check is identified by the separation of fibres along the grain observed on longitudinal surfaces or on end surfaces, and measured by length and width of maximum separation of fibres; and rarely by its depth, as it is commonly believed that the width gives an indication of the possible depth also. When the width is less than 2 mm and the checks are numerous

on any surface, they are evaluated on the basis of their average length and the affected area on the surface, expressed as a percentage of the whole area on which they appear. Checks more than 2 mm in width are evaluated as shakes on the basis of length and width. For lengths of average checks varying from 5 cm to 50 cm, the range of defect values, according to IS :3364-1965, for the different precentages of the affected are as, are given below :

Affected area expressed as a percentage of whole area	Defect units for checks ranging from 5 cm to 150 cm
20%	0.01 to 0.1
40%	0.02 to 0.2
60%	0.04 to 0.4
80%	0.08 to 0.8
100%	0.16 to 1.6

(ii) *Decay* or *rot*.—This is identified as brownish or light-grey patches on the surfaces of the material, and the condition of dicay is judged by the degree of softness as detected by the relative ease of penetration of a sharp knife or similar tool. The decay is estimated by the approximate area of the section on which it is seen and is expressed as a percentage of the entire section. The units of defect for decay and rot, ranging from 1% to 50%, vary from 0.01 to 0.50, and if more than 50% of the area is decayed the piece is rejected.

(iii) *Flutes*.—These are identified on the surface of a log as longitudinal depressions and are measured by their lengths on the longitudinal surface and the depths at their maximum points (i.e., between the bottom of the flute and a tape taken round the log). The depth is sometimes expressed as a percentage of the girth of the log. Defect units for the lengths of flutes varying from 0.5 to 5m, for the different depths of flutes, are given below :

Depths of the flutes	Defect units for lengths of flutes from 0.5 to 5 m
5 cm	0.04 to 0.34
10 cm	0.06 to 0.66
15 cm	0.10 to 1.00
20 cm	0.14 to 1.34
25 cm	0.18 to 1.66

(iv) *Holes*.—There are different types of holes caused by insects, birds, mechanical injuries, etc. Excepting pin-holes, the others are generally expressed by their diameters. When in large numbers, their number per given area of the surface, say 100 sq cm, describes the limits in the various grades. While in some of the earlier specifications in India they were designated as "small holes" and "large holes" with suitable limits of the diameters, the present tendency is to evaluate them quantitatively in terms of defect values as below :

Defect values for holes

Concentration of holes per 100 cm² not more than	Diameter of the largest hole in any concentration	
	up to 5 cm	above 5 cm and up to 10 cm
1	0.01	0.03
2	0.02	0.06
3	0.03	0.09
4	0.04	0.12
5	0.05	0.15

(v *Inbark.*—It is identified as patches of bark or other material, partially or wholly enclosed inside the wood, and is measured and evaluated in the same way as knots described below.

(vi) *Knot.*—This is identified as the basal portion of a branch which was earlier cut off from the stem; bark appears as part of the embedded material. Knots are usually oval or circular in shape. The "maximum diameter" of a knot is taken as its size and this along with its form and position in the material describes the knot. The defect values of sound knots are quantitatively evaluated in terms of the number of knots present on a surface and the mean of the maximum diameters of all the knots. For knots ranging from 1 to 15, the defect values for the ranges of different diameters are given below. Double values are taken for unsound and decayed knots :

The mean of the maximum diameters of knots	Defect values for knots ranging from 1 to 15
Up to 5 cm	0.01 to 0.38
5 to 10 cm	0.04 to 1.50
10 to 15 cm	0.08 to 3.00
15 to 20 cm	0.10 to 4.50

(vii) *Shake.*—This is identified on the cross-section of the material as a partial or complete separation between adjoining layers of tissues and is classified as heart-shake, ring-shake, cup-shake and star-shake. All shakes, except star-shakes, are measured by the length and maximum width of the opening. The latter also serves as an indication of the approximate depth of the opening. Defect values, for lengths of shakes from 2 cm to 20 cm, are given below for different widths applicable to material whose area of cross-section does not exceed 0.5 sq m. For materials of larger cross-section, the defect values are halved. In the case of star-shakes, the largest shake is taken into consideration, but the defect values are multiplied by half the number of shakes of the star to get the total value for the entire star-shake.

Width of the shake in cm	Range of defect values for shakes ranging from 2 cm to 20 cm
0.2	0.06 to 0.66
0.6	0.06 to 0.86
1.0	0.10 to 1.20
2.0	0.12 to 1.52

(viii) *Spiral grain.*—In a log, this is identified as the grain on the surface spiralling along its length, and is measured by the acute angle it makes with the axis of the log. This is also known as twist of the tree. It is described either as "clockwise" or "anti-clockwise" i.e. "right-handed" or "left-handed", depending upon the direction of progress of the spiral from butt to the top as viewed from the top end (i.e., the smaller end of the log). Twist is quantitatively evaluated as below, and slopes below 5 degrees are ignored.

Slope in degree	Defect value
5° to 10°	0.20
11° to 20°	0.45
21° to 30°	0.65
31° to 40°	0.80
41° to 50°	0.90
above 50°	1.00

Twist or spiral grain is also measured as a gradient, expressed as the ratio of the two sides of a right angle, one parallel to the axis and the other tangential to the circumference of the log, with the spiral serving as the hypotenuse.

(ix) *Split.*—Split is identified as a separation of fibres as seen both on the cross-section and on the longitudinal surface of the material. It is measured by the length on the longitudinal surface and by the depth on the end section. For the different lengths of the splits, ranging from 0.25 m to 4 m, the range of the defect values for the different depths of the splits at the end surface are given below, for material upto a length of 10 m or fraction thereof.

Depth of split at the end surface in cm	Defect values for splits of lengths ranging from 0.25 to 4 m
1	0.06 to 0.80
2	0.06 to 1.06
3	0.10 to 1.46
4	0.12 to 1.86

(x) *Cross grain.*—This is primarily a defect of converted material, and includes different types such as spiral grain, diagonal grain, inclined grain and slanting grain. Cross grain is identified by the inclination of the fibres on the surface of the material, and is measured by the slope of the grain on the surface to the edge of the piece. When it is present on two adjacent surfaces the combined slope is given by the equation :

$$\frac{1}{X^2} = \frac{1}{A^2} + \frac{1}{B^2}$$

where

$\frac{1}{A}$ & $\frac{1}{B}$ are the slopes on the two adjacent surfaces, and

$\frac{1}{X}$ is the combined slope.

It is quantitatively evaluated in the same way as spiral grain in logs mentioned above.

While the above defects for logs and converted material are quantitatively evaluated as indicated above, their permissible limits will form the subject of individual specifications for various uses. In logs no quantitative evaluation is done for crooks, pitch-pockets, sapstain etc. Similarly, no quantitative evaluation is done in converted timber for such defects as distortion (i.e. warp which includes bow, cup, twist), streaks (which include black streak, gum streak, mineral streak, pitch streak, and radial streak), texture and wane. Defects not mentioned above but which may cause degrade in further utilization may have to be taken as "equivalent defects" for purposes of measurement and quantitative evaluation. The estimation of defect values in such cases is guided by their appearance, size, location and distribution with reference to the whole material. With the presence of the other features, which cannot be considered as equivalent defects but are definitely recognised as those which reduce the utility of timber, a value of 0.10 is added to the total defect values for safety.

All linear measurements of defects are corrected to one millimetre and surface area measurements are calculated correct to 1 sq cm. The units of defects are evaluated correct to the second decimal place. Where ready figures for the values are not available, an estimate is generally made from the pattern of values mentioned in various tables above. All defects are expected to be evaluated on the basis of 10 m length of the material. In the case of logs, they are further expected to be cylindrical, with all projections dressed down to the cylinder (which by definition would mean that any diameter at any cross-section of the log shall not be less than 80% of the maximum diameter in the entire log). In the case of converted timber, the same is expected to be squarely sawn to a fairly smooth surface.

Guiding principles for visual inspection of timber

While any specification or set of rules can provide for maximum conditions of defects and/or defect values permissible in a given grade, it does not mean that any individual piece, having any one of the defectts slightly in excess of permissible limits, should always disqualify the material for acceptance. It also does not mean that a material having all those defects which are permissible for a grade should necessarily always qualify for the particular grade. It is well recognised that location, distri-

bution and combination of the same with other defects are important in the final acceptance and determination of the grade. The total absence of one defect may sometimes permit a lenient view of another defect. By and large, grading of many materials is done for a whole consignment and not always for individual pieces only.

If on completion any inspection, identical certificates are issued to the seller and the buyer, they would form a proper basis for agreements and settling disputes. All deviations and factors leading to personal discretion should be clearly mentioned in such certificates of inspection. The standard of inspection may become the subject of examination by an authority which should be specifically mentioned in contractual agreements. Where a re-inspection of a consignment becomes necessary, a small latitude of, say, 5% is generally allowed for personal judgement of the inspectors.

The grading specifications of timber and timber products cannot be said to be the results of any highly developed mathematical calculations, but are usually a collection of different aspects of a material product, based on available experience, brought on as close as possible to a technological pattern. The specifications would primarily serve as guiding factors for the inspectors to take spot decisions which may again be subjected to a proper assessment by a higher technical authority. While no rules for inspection can be maintained with complete satisfaction, owing to usual variations between the rule and the actual practice, the judgment of the inspector or grader should be such as to command the maximum degree of acceptance by all concerned.

The normal ethics for grading would include the avoidance of regrading of same material without further conversion or alteration, and would presuppose an unbiased compromise between the availability of the material and its end use.

Stress grading and structural grading

The terms 'stress grading' and 'structural grading' are quite often used synonymously. However, sometimes, a small distinction is made between the two, stress grading referring to the principle under which species or materials are graded only by consideration of the principal stresses to which the material is likely to be subjected, and structural grading referring to the principle under which species or materials are graded on the basis of visible defects which may have known effects on the strength properties of the material. Thus, in both the cases, systematic studies of the influence of various defects on strength of wood furnish the basis for this type of grading. The strength ratio of a grade is defined as the percentage ratio of the strength of the material of that particular grade to that of clear wood free from defects. In other words, it is the ratio expressed as a percentage of working stress of the grade to the working stress of defect free timber, sometimes referred to as *basic stress*. The purpose of this system of grading of timber is to provide meterial of more or less uniform strength for a particular type of use in constructions.

In India, structural timbers for building purposes are classified into four grades, namely, Select Grade, Standard Grade, Common Grade and Structural Rejects. Timbers of select grade contain defects, the estimated effect of which tends to reduce the basic strength of timber by not more than 12.5%. The safe working stresses for timbers of this grade are 7/6 times the safe working stresses for timbers of standard grade (Limaye, V. D. 1946). Timbers of standard grade contain defects, the estimated effect of which tends to reduce the basic strength of timber by more than 12.5% but less than 25%. Timbers of common grade contain defects, the estimated effect of which tends to reduce the basic strength of timber by more than 25% but less than 37.5%. The safe working stresses of this grade are 5/6 times the safe working stresses of timbers for standard grade. Structural rejects are those which contain defects, the estimated effect of which tends to reduce the basic strength of timber by more than 37.5%, but otherwise acceptable from the point of view of appearance and utility. Timbers of this grade are not used as structural members coming under stresses. In the Indian Standard 1629-1660, leaving the Select Grade as it is, the Standard Grade is referred to as Grade I (Structural), and the Common Grade is referred to as Grade II (Structural). While it is not possible to evaluate from physical inspection the exact reduction in basic strength due to various defects, the standards generally prescribe the maximum permissible defects for one grade and limit the same proportionately in the other grades, e.g., the knots permissible in standard grade are given in Table V-1, and the permissible slope of grain is 1 in 15. In the select grade, defects only half as large as those permitted in standard grade are allowed and the slope of grain is limited to 1 in 20. In the common grade, defects only 1½ times as large as those permitted in standard grade are allowed and the slope of grain is limited to 1 in 12.

In addition to the above considerations for classification of timbers in different grades on the basis of defects, there are other criteria also which limit the use of timbers for structures. For example, according to the Indian Standards, light timber having a weight less than 75% of the average weight of the species is not to be used for structures. Similarly, timbers with loose grain, splits, compression wood in coniferous timber, heartwood-rot and sapwood-rot with holes containing live infestation, etc., are not allowed in structural timbers. Wanes are permitted provided they are not combined with knots, and the reduction in strength on account of the wane is not more than the reduction with the maximum allowable knot. Wanes are also permitted if there are no objections to their presence at the bearing areas and nailing edges, and to the general appearance.

TABLE V—1

Defects permissible in Standard Grade

Width of face	Maximum size of live knots	
	Narrow face and 1/4 of the width of wide face close to top and bottom edges	Central half of the width of the wide face
mm	mm	mm
75	19	19
100	25	25
150	38	38
200	44	50
250	50	57
300	54	75
350	57	81
400	63	87
450	66	93
500	69	100
550	72	103
600	75	106

Classifying the species as a whole on the basis of their strength, three groups are recognised in Indian Standards as "super group", "standard group" and "ordinary group". Under the "super group", the Modulus of Elasticity of clear timber is more than 126,000 kg/sq cm and the Modulus of Rupture more than 180 kg/sq cm. In the "standard group", Modulus of Elasticity is less than 126,000 kg/sq cm but more than 98,000 kg/sq cm; similarly, the Modulus of Rupture is more than 120 kg/sq cm. In the "ordinary group", the Modulus of Elasticity is less than 98,000 kg/sq cm but more than 56,000 kg/sq cm and the Modulus of Rupture is more than 85 kg/sq cm. Sometimes species are recommended for use in various situations, as first choice and second choice in permanent structures or in temporary structures, depending upon their durability and treatability. Among the common Indian timbers, khair (*Acacia catechu*), black siris (*Albizzia odoratissima*), hopea (*Hopea* spp.), mesua (*Mesua ferrea*), red-sanders (*Pterocarpus santalinus*), and sal (*Shorea robusta*) fall under the "super group"; benteak (*Lagerstroemia lanceolata*), bijasal (*Pterocarpus marsupium*), teak (*Tectona grandis*), babul (*Acacia arabica*), laurel (*Terminalia tomentosa*), kindal (*Terminalia paniculata*) and axlewood (*Anogeissus latifolia*) fall under the "standard group"; jack (*Artocarpus integrifolia*), deodar (*Cedrus deodara*), haldu (*Adina cordifolia*), mango (*Mangifera indica*), fir (*Abies pindrow*) and spruce (*Picea smithiana*) fall under the "ordinary group".

Machine grading

Visual methods of stress grading described in the above paragraphs have naturally several drawbacks. In the first instance, the measurements and evaluation of defects depend only on external visible features. The hidden features and the hidden defects cannot be properly estimated. The estimation of cumulative effect of defects based on the above lines is still arbitrary in its nature. To avoid subjectivity in the field of stress grading and to give the engineer the necessary confidence in the use of timber, a need has arisen to mechanically grade the timber on a suitable machine.

Contrary to earlier belief, recent investigations have revealed that Modulus of Elasticity of a given piece has a direct correlation with ultimate strength of the material not only in defect-free specimens

but also in specimens with normally acceptable defects. It is on the basis of this relationship between stiffness and strength (i.e., between Modulus of Elasticity and Modulus of Rupture) that machine stress grading has come into vogue. In this connection, two types of machines have been developed so far; (1) the 'Deflection type' which is based on the principal that, if a fixed load below tha elastic limit is applied, the deflection is inversely related to Modulus of Elasticity, and (2) the 'Vibration type' in which the transverse vibrations project the Modulus of Elasticity through a system of photo-elastic devices and electronic counters. While the former has already come into wide use in several countries, the latter is still in infancy.

Economy due to grading and rational utilization

A review of all the efforts to introduce grading and selection of species in several specifications, particularly those of Indian Standards Institution, amply justifies the role grading plays in the economy of tibmer utilisation in the country. While it is not intended to discuss in the present chapter the detailed extent of economy that has been obtained or can be obtained due to each individual grading specification, an attempt is made here to bring out some general conclusions with particular reference to conversion of logs, avoidance of wastage, and structural grading. For example, grading according to IS : 1331-1958 specification for cut sizes of timber has not only brought out a clear distinction between battens, planks, scantlings and baulks in terms of the limitations on the cross-sectional dimensions but has also reduced the numerous sizes that originally existed in the trade to only a few limited number of "standard sizes" for stocking purposes under the different heads mentioned above. Even this classification has been further reduced to three groups as "mostly used", "commonly used", and "occasionally used" sizes, which in the international standards are known as "preferred" and "non-preferred" sizes. (I. S. O. : 1967). Thus, the commonly used planks, for example, are only ten of three standard thickness of 25 mm, 38 mm and 50 mm and ranging in width from 150 to 225 mm. Such a rationalisation of the dimensions for stocking purposes has not only reduced stacking and storing expenses but has also clearly paved the way for a free flow of the expected supply and demand. It has also helped to reduce wastages in conversion of logs by enabling fixation of the optimum diameters of the logs required for obtaining the given sizes of "standard" planks and the optimum yield that can be expected from given diameters of logs under the normal methods of log conversion now prevailing in the country. Thus it has been possible to evaluate what should be the correct sizes of the standard planks to be taken out from the given diameters of logs for obtaining the maximum yield with the least wastage. (Sekhar : 1965)

Similarly, in grading timbers intended for structural purposes such as purlins, rafters, beams posts, etc., several species as stated before have been grouped together under the three heads as 'super", "standard" and "ordinary" in IS : 883. Such a specification in grading has not only permitted a proper choice of material for different limitations of stresses but has also provided easy selection of alternatives where material of one species may be in short supply, without reducing confidence in the design of any structure. However, IS : 1629-1960 prescribes in a comprehensive manner the general rules for grading of cut-sizes of timber, both for structural and non-structural purposes, and places the material under different grades on the basis of defects. With the adoption of these standards in the design and fabrication of timber, the expected saving is estimated to be about 50% when compared to conventional methods (Raman : 1965).

Besides the above, there are also other specifications such as IS : 2179, 2203, 2372, etc., which deal with the specific species for particular purposes and sometimes group them according to defects and the required dimensions for permissible loads. By the help of these specifications, and grading of the species for their rational use, the timber trade and industry have generally achieved comparative economy in selection of alteranative species, and has become more organised in the recent years as compared to conditions existing during the years 1940 to 1950. There has also been an increasing appreciation of the value of forest wealth and its contribution to national economy. Policies of wood industries are getting more clearly defined in the context of rationalisation of the demand and future planning has become comparatively easier. Table V-2 indicates how between 1951 and 1964 the timber trade has grown with standardisation and grading concepts, and gives a general idea of industrial production in India.

Unlike in other countries, there are at present no organised efforts in India either for imparting a systematic theoretical and practical training in grading of timber, or for establishing any central organisation for the authoritative issue of grading rules, interpretation of grading clauses of the various specifications, or issue of certificates. Great reliance is still placed on conventional practices and the limited technical knowledge of local inspectors. In several foreign countries, there are Government or non-Government organisations which issue institutional certificates to the graded material, inspected by a well recognised and authoritative grading service. Remembering that in this country the different specifications existing in different organisations were drawn up mostly by departmental interests, with

TABLE V-2

Standardisation and grading indices as compared to indices of Industrial production.

Base 1956=100 in the columns where indicated.

Year	General index of Industrial production	Trade in wood	Growth of Indian Standards	Approximate number of Indian Standards in wood and wood products
1951	73.0	55.3	25.6	4
1955	92.3	87.87	76.9	26
(1956)	(100)	(100)	(100)	—
1960	130.2	147.8	185.9	63
1961	139.4	150.2	217.9	68
1962	149.7	162.4	250.0	75
1963	163.6	194.8	285.2	93
1964	174.0	201.0	326.9	111

varying degree of experience and knowledge, it seems that there is an absolute need not only for uniformity but also for a recognised authority to solve disputes, correctly assess permissible defects, and interprete individual grading clauses. An organised course of training in timber grading is one of the essential missing links in the successful utilization of timber and timber products.

Note :—Some sample specifications of timber and grading rules are given in Appendix VII (a) to (d).

REFERENCES

F. A. O. 1958 Asia-Pacific Regional Grading Rules for Teak Squares.

Howard, S. H. 1927 Forest Pocket Book. The Supdt. Govt. Press, U. P., Allahabad.

I. S. O. 1968 Revised coniferous sown timber sizes, tolerances and shrinkage, methods of measurement etc. ISO/TC. 55.

Limaye, V. D. 1944 Suitability and selection of timber for different uses, Pt. I and II, *Indian For. Rec.* (N. S.) Utilization—Vol. 3 (5).

Limaye, V. D. 1946 Safe Working Stresses for Indian Timbers, *Indian For. Rec.* (N. S.) Utilization—Vol. 4 (1).

Limaye, V. D. 1954 Grouping of Indian Timbers and their properties, uses and suitability, *Indian For. Rec.* (N. S.) Timber Mechanics Vol. 1(2).

Raman, S. P. 1965 Role of standards in timber in dustries, *Foreign Trade Journal* No. 24.

Rehman, M. A., Purushotham, A. & Sekhar, A. C. 1956 Timber as Building Material; Symposium on Building Materials, New Delhi.

Seaman, L. N. 1924 Interim report on the work under Projects No. 1 and No. 0 by the Section of Timber Testing including the result of the Mechanical and Physical tests on certain of the commoner Indian Timbers upto end of 1922, *Indian For Rec.* Vol. 10. Part VII.

Seaman, L. N. 1934 Tentative grading rules for structural timbers, *Indian Forester,* Vol. 60 (3).

Seaman, L. N. & Limaye, V. D. 1935 Rules for the grading of Teak Squares; Manager of Publications, Delhi.

Seaman, L. N. & Ranganathan, C. R. 1926 Second Interim Report on the work under Project No. 1 by the Section of Timber Testing including the results of the Mechanical and Physical tests on certain of the commoner Indian Timbers upto end of 1924, *Indian For. Rec.* Vol. XII, Part III.

Sekhar, A. C. 1957/62 Note on Grading of timbers in India; British Commonwelath Forestry Conference, New Zealand (1957). Revised and reprined in the *Journal of Society of Indian Foresters,* Vol. II, No. 1 (1962).

Sekhar, A. C. 1960/62 A note on some recent trends in teak utilization in India; presented to "Teak Sub-commission" Asia Pacific Forestry Commission, 5th Session, New Delhi (1960). Revised and Reprinted in the *Journal of Society of Indian Foresters,* Vol. II No. 2 (1962).

Sekhar, A. C. 1965 Grading as an aid in Timber Economy; presented to Ninth Indian Standards Convention-Special Supplement.

Sekhar, A. C. 1965/66 A method of evaluation of wood quality on the bais of utilization characters; presented to IUFRO in Oct. 1965.

Sekhar, A. C. 1966 Recent trends in evaluation and standardization in wood an wood products as an aid in planning for industrial development in India; presented to VI World Forestry Congress, Madrid (Spain).

Sekhar, A. C. & Sharma, R. S. 1967 Practical application of shrinkage values in grading of timber, *Indian Forester,* Vol. 93 (2).

CHAPTER VI

SYSTEMS OF EXTRACTION AND DISPOSAL

The different systems of extraction and disposal of forest produce can be classified under three main heads :

(1) By Government agency.
(2) By Government and purchasers combined.
(3) By purchasers alone.

The choice of an appropriate system for a given locality will be decided by a number of considerations of which the following may be mentioned :

(a) Forest maintenance and improvement.
(b) Profitability to Government.
(c) The scope for theft or fraud by forest employees or purchasers.
(d) The legitimate interests of the local population.
(e) Complications, if any, involved.
(f) The physical conditions of the locality.
(g) The strength and qualifications of forest staff.
(h) The quality and quantity of labour available.
(i) The capabilities and financial standing of contractors and purchasers.
(j) Encouragement, if need be, of private enterprise.

The relative importance of any of these factors will differ from place to place, and a choice should be made on merits with reference to the peculiarities of each case and each set of circumstances.

Working by Government agency

Under this system, the extraction and disposal of timber and other forest produce are carried out directly by the forest department itself, the net profit being the sale value less the working expenses. In general outline, the system consists in the extraction being done by persons working on behalf of the department, the subsequent sale being made by the department. This is practised in certain parts of the country, e.g., Madras, Kerala, Mysore, etc., particularly for extraction of valuable timber, e.g., rosewood (*Dalbergia latifolia*), sandalwood (*Santalum album*), teak (*Tectona grandis*).

The usual method of departmental extraction is for the forest department to pay contractors to fell, convert and transport the timber to a sales depot. The work is paid for at rates stipulated in the contract for felling, conversion, carriage and delivery at a certain spot. Strict supervision is necessary over every detail of a contractor's work. The measurement and counting of timber for final payment must also be carried out by a reliable officer, and very careful record of logs passed and paid for must be kept to prevent fraud. It often becomes necessary to give advances to contractors; this is regulated by departmental rules.

The following are some of the advantages in departmental extraction :

(1) All operations are carried out directly under the control of the forest officer.
(2) It is specially useful where regular supplies are necessary or prices have to be kept down because of the scarcity of forest produce.
(3) It may be employed where a new industry has to be started or a new product has to be placed in the market.
(4) It can be well employed if Government fails to get the full benefit from any other system.

The main drawbacks of the system are :

(1) The large amount of executive and clerical work involved.

(2) The commercial nature of such work which, by and large, is better suited to private enterprise than to Government agency.

The policy of Government has for long tended to limit departmental extraction, and encourage extraction by purchasers wherever possible. The present emphasis on eliminating middlemen as far as possible may bring departmental working into greater prominence.

As a rule, minor forest products are not extracted by departmental agency, but, where public interest so indicate, the extraction is sometimes done departmentally, e.g., the collection of pine resin in the Himalayas. In this case, the detailed nature of work would never be complied with by an outside contractor, and in the interest of the forests themselves it is advisable for Government to keep the work in their own hands. The exploitation of tribal labour by contractors has lately led to the collection of certain minor forest produce being leased out, in some places, to tribal co-operative societies.

Working by Government and purchasers combined

This system is sometimes adopted when it is in the interest of Government to have control over part of the work. As an example, it is often necessary that great care should be taken during fellings to avoid damage to the forest, and in such cases the actual felling of the trees may be done departmentally, leaving the further conversion, transport and sale of the timber to the purchasers. This system has been adopted from time to time in India. It may be usefully employed in the case of thinnings and improvement fellings; the felling will be done by skilled departmental wood-cutters so as to ensure that no inferior or harmful trees are left and that as little damage as possible is done to the growing stock; the felled material will be removed by purchasers.

Working by purchasers alone

This is by far the most common system of working adopted in India. There are many forms of the system, distinguished mainly by the different ways of payment, and these will be dealt with under "Systems of sale of forest produce".

The advantages of this system are :

(1) It encourages healthy competition; and

(2) It relieves the forest staff of much work. This is a matter of no small importance in India where the staff have large areas to look after and can be far more usefully employed in the maintenance and improvement of the forests than in being tied down to the execution of work that could possibly be done better by private enterprise.

To prevent malpractices and enforce strictly the conditions of the contract, particularly those pertaining to the silvicultural aspects, close supervision will be necessary. In the absence, however, of any serious silvicultual problems, and provided there is no lack of demand of competition from purchasers, working through purchasers is perhaps the most satisfactory system, under conditions that obtain in our forests.

Systems of Sale of Forest Produce

The different methods of selling timber and other forest produce may conveniently be grouped under the following two heads :

(1) Lump-sum sales.

(2) Payment on outturn.

Lump-sum sales

Under this head come all systems of sale in which a fixed sum is paid for the produce in question, whether the exact quantity of such produce is known or not. The following are some examples of lump-sum sales :

(1) The sale of the right to collect and extract forest produce in a forest for a fixed sum, the exact amount of produce involved being unknown at the time of the sale; the purchaser can

extract as much produce as he can. This practice is particularly common for the sale of minor forest produce.

(2) The sale of certain marked trees for a lump-sum payment. The sale price may be realised in one or more (usually three) instalments, the first instalment being collected before the work is started or any part of the produce is removed.

The system has both advantages and disadvantages depending on the actual circumstances of each case. Where the quantity of produce involved is known, the securing of a fair price can usually be ensured; where it is unknown, the risk would be thereof the sale amount being too low. Often, however, it is the only means of getting certain kinds of produce extracted.

Payment on outturn

Here the sales are based on the actual quantity of produce involved. There are many varieties of this sale, including the well-known royalty systems in which the purchaser pays an agreed amount per unit of produce extracted. The royalty may be on volume, weight, quantity or *ad valorem*, and may or may not include a guarantee of the expected outturn. Methods of working are, however, closely inter-connected with systems of sale, and the more common Indian methods of working and sale are given below :

(1) *Sale of a whole coupe or area.*—In this case the sale consists in disposing of to a lessee, for a fixed period, the right to extract timber or other produce from a given forest area; the period is usually one year but may occasionally be more or less. The sale value is realised usually as a lump-sum, or by payment or royalty on the quantity of produce actually extracted, or by a combination of both. The simplest form of lease is that in which a lump-sum is paid for the privilege of extracting all the available produce of a certain kind within the stipulated period. This is admirably suited to the sale of produce from areas to be clearfelled, such as coppice coupes, regeneration areas, etc. It is also suitable for the sale of such annual crops as grass, fruits of trees such as myrobolan (*Terminalia chebula*) and tamarind (*Tamarindus indica*), and : other minor products such as honey, wax, lac, etc., in such cases it is sometimes known as 'farming', and is conveniently employed as there is normally little risk of the future crops suffering from such a form of collection.

(2) *Sale of marked standing trees.*—This is one of the most suitable and profitable methods. The trees are selected and marked, and the whole outturn is sold. Payment may be in a lump-sum by instalments, or based on royalty on outturn. The number and cubic contents of the trees sold may or may not be known when the contract is made. The price will be influenced by the situation of the trees (which affects the cost of extraction), the prevailing market rates of timber, and, where the outturn is estimated in advance, the purchaser's view as to whether the official estimate is high or low.

A well-known form of this method is the 'monopoly system'. Here the purchaser gives a price, known as the monopoly price, for the right to fell and extract timber. In addition to this payment, however, he has to pay a fixed royalty on all the timber brought out of the forest. One disadvantage of this method is that the purchaser is not induced to remove inferior timber if the royalty rates are high. The method has, however, the advantage of inducing removal of everything profitable to the contractor if the royalty rates are kept low. The fixing of royalty is not an easy matter, as extraction costs may vary considerably in different parts of a forest; unless judiciously done, it may tend to induce concentrated removals in certain parts where the royalty works to a profit and neglect where it does not. For this reason, it is often better to dispense with royalty and confine the sale to lump-sum purchase : it is then in the interest of the purchaser to bring out all the timber he can, whether good or bad.

(3) *Sale by means of licences and permits.*—This method, in its varied forms, was formerly widely prevalent in India, but is hardly in vogue now except for the removal of specified classes of trees in unreserved forests and grass, thorn and similar petty produce, grazing, shooting, etc., in reserved forests. In the most typical form of this method, the intending purchaser applies for a licence to extract timber or other forest produce in a specified area during a fixed period of time, pays a prescribed fee, and collects and extracts his produce on terms stipulated in the licence. The exact amount of produce that can be extracted, the locality of extraction, etc., should be specified in the licence.

A common modification of this method is that known as the 'commutation system', in which the issuing of many licences or permits for short periods to several persons is commuted by one payment. It is very useful for issuing permits to villagers to extract petty forest produce, e.g., thorns for hedges, litter, grass, forest grazing, etc., as instead of having to issue many separate permits to individuals one permit for a whole village can be issued, thereby saving considerable trouble in checking and supervision. This practice is not ordinarily extended to valuable products except for bonafide domestic purposes, and that too only for short periods.

METHODS OF SALE

The common methods of selling forest produce are given below :

(1) By negotiation (or private bargain).

(2) By fixed tariffs.

(3) By auction.

(4) By tender.

By negotiation (or private bargain)

This method, so common in ordinary business transactions, is exceptional in forest works. It is applicable only under special circumstances such as those mentioned below :

(1) Supply to a person or firm of produce for which there is no general demand, e.g., a few selected trees or logs required for some particular industry. The price may be fixed according to prevailing market rates or on the basis of past sales, or, if the present or past price is not known, at the discretion of the authority concerned. The acceptance of a low price for produce for which there is no demand may help to create a market for it.

(2) Breaking up 'rings' or combinations of buyers at auction. On several occasions, this method has resulted in the discomfiture and collapse of organized rings of timber buyers who tried to force down prices of produce in auctions.

By fixed tariffs

In this method of sale, prices are fixed before hand and cannot be altered except with official sanction. Therefore, the prices must more or less tally with current market rates, and be revised from time to time accordingly. The method is often employed for inferior timber, firewood, and bamboos and other minor forest produce. It is widely adopted in depots, as it needs very little supervision and, except for periodic checking of stocks and sales, can be conducted by subordinate staff.

The royalty system is really an adaptation of this method of sale, the royalty being a fixed tariff on particular produce extracted from the forest.

By auction

In auction sales, intending purchasers go on increasing the price they are prepared to offer until no one offers any more, and the highest price offered is accepted as the sale price. If there is enough rivalry and competition, auction sales are very satisfactory and profitable, and are widely adopted for the sale of forest produce. The one disadvantage is the danger of combinations or rings being formed, which will come in the way of healthy competition and brisk bidding. If this happens, the auction has to be stopped and sale by tender or negotiation resorted to. Combinations are largerly checkmated by giving the sales wide publicity, so as to ensure the presence of purchaser from a distance who have no connection with local rings. An upset price, below which no bids are accepted, is generally fixed at the sales.

By tender

This method consists in intending purchasers offering, on or before a fixed date, the price they are prepared to pay for the product in question. There are two different forms of tender, viz., 'sealed tenders' and 'open tenders'. In the case of sealed tenders, the intending purchasers submit their tenders in sealed covers, with the result that no other would-be purchaser knows what the offer is. In the case of open tenders, offers may be made either personally or in writting; the price offered becomes known to every one interested and this may result in bargaining or combining. It is, however, a profitable method for produce whose value remains fairly constant. Sale by tender is an effective method for breaking up combinations. It is, however, not always so profitable as other forms of sale, particularly auctions, but as the right to accept or reject any tender is always reserved by the seller, it gives the seller the advantage to disregard doubtful or undesirable tenders and select the buyer.

CHAPTER VII

ORGANIZATION OF FOREST LABOUR

Scope for employment in forests

Forests provide manifold opportunities for various kinds of employment. A vast permanent property like the forest estate of India calls for, besides an adequate administrative and managerial establishment, a large labour force. Systematic forest management involves the execution of many different types of works, such as forest protection and regeneration, felling, conversion and extraction of timber and fuel, collection of minor forest products, construction of roads and buildings, etc. These works provide employment for many skilled and unskilled workers, whole-time and part-time. The availability of a very large, under-employed rural population, besides forest-dwelling tribes, in the neighbourhood of forests, with no settled means of livelihood, has led to the forest department resorting to this source of labour, mostly on daily wages, for almost all works. Inevitably, this has resulted in continued dependence on what is largely unskilled labour for most works, whether it be for felling trees, sawing timber, collecting, carting or extracting produce, or making tracks or roads in the forests. As such, labour seeks employment in forests mostly in the non-agricultural seasons; there is onsiderable difficulty in procuring labour for such forest operations as sowing, plantings, weedings etc., which are usually carried out during the agricultural seasons. Other operations, such as felling and extraction can however be arranged to be carried out in the off-season for agriculture. Apart from works in the forests themselves, many people find employment in forest-based industries, some of them of a large scale, some of a small scale, and yet others of the nature of cottage industries.

Labour in forest works

Vast numbers of *mazdoors* are employed by the forest departments in fellings, thinnings, tending, climber-cutting, seed collection, nursery and plantation works, fire-protection, etc. In the exploitation of forests, forest contractors play a large part, employing labour of their own. All in all, the average number of persons employed daily on a whole-time basis in the forests of this country is estimated to be over 250,000 and the average number who further depend on the forests daily for part-time employment to be over 270,000. Thus the strength of casual or seasonal labour is far greater than that of regularly employed labour. This seasonal labour in most localities is readily available between the planting and harvestng of agricultural crops and in the fallow seeaons. The slack season in Indian agiculture luckily coincides fairly well with the busy season in most forestry operations in some regions, while it is exactly the reverse, at least for some operations, in other areas.

The local population in the undeveloped and under-developed areas in and around the hills, including the tribal population, depend for their livelihood largely, sometimes entirely, on their earnings from forestry operations. In these circumstances, it is not surprising that mechanization of forestry operations has hardly made any progress in India. In fact, the only forest work in which mechanisation has at all progressed is in the transport of forest produce by motor lorries, which have largely replaced the age-old bullock-carts. In parts of the Himalayan forests, even today the practice prevails of timber being brought out of the forests pickaback by labourers.

Labour in forest-based industries

Forests support a number of industries, which is in turn afford employment on a regular basis to skilled workers and craftsmen as also to unskilled labour. Among the major organised industries in this field may be mentioned the paper industry (about fifteen large units in different States), the mechanised match industry, mainly the Western India Match Company Limited, the sawmill industry, the rosin and turpentine industry, and the ply-wood industry. Small-scale industries include the battery-separators industry and the sports-goods industry in Upper India, the textile-mill-accessories industry in

Maharashtra and Gujarat, the sandalwood-oil industry in Mysore, the *katha* industry in Uttar Pradesh and Madhya Pradesh, the pencil industry and the furniture industry. The extent of employment afforded by the large and small-scale industries is exemplified by the position in Uttar Pradesh, where 5,350 persons are engaged on a regular basis in such industries. With the growth of forest industries, the extent of such employment is bound to increase a great deal, but even so, these industries will not benefit the forest-dwellers or the rural folk living near forests, so long as they are located away from the forests.

A great variety of cottage industries dependent on forest produce have existed traditionally in most parts of the country, affording spare-time occupation and employment to a vast population. While it is difficult to ascertain their importance in terms of the number of those so employed, or the resultant additions to their income, it may be confidently stated that they play a vital role in the rural and even urban economy of the country, and permeate significantly the very life of the people. Among the more important of such industries are : the rearing of silk-worms on forest trees and silk spinning and weaving in Assam; the cultivation of lac in several States; the manufacture of wooden toys in many parts of India; the manufacture of *beedis* (indigenous cigarettes rolled in leaves) in Uttar Pradesh, Madhya Pradesh, Andhra Pradesh and Madras; the tanning of leather, using a variety of tan barks, fruits, etc.; from forest shrubs and trees; the manufacture of *katha* in forest locations in Uttar Pradesh, Madhya Pradesh, Bengal and Assam; making of handmade paper; production of essential oils like lemon, grass oil, rosha grass oil, vetiver oil, etc.; the manufacture of baskets and other articles from bamboo and cane; and rope-making from forest fibres. Mention must also be made of the well organized production of matches in Southern India on a cottage industry basis.

Availability of labour for forest works

In India, local conditions of labour vary much from place to place; in some localities little difficulty is experienced in obtaining labour for forest works, while in others it may be a formidable task to collect experienced workers.

Forest dwellers, and those living in the periphery of the forests, usually make the most satisfactory workmen for they are born to a forest life. As, however, they are mostly agriculturists, they are readily available for forest works only in seasons when they are free from the actual planting or harvesting of crops, and there is a marked scarcity of labour during the periods when agricultural operations are in active progress.

In hill districts, the population is often so sparse that it is necessary to import labour from the plains. In the Himalayas, it is usual to import labour through the agency of a contractor who is paid a commission which is a percentage of the earnings paid to the workmen.

Types of labour

Forest labour can be broadly divided into two types : (i) local labour and (ii) imported labour.

(i) *Local labour* is often of a casual and fluctuating nature, and is secured from adjoining villages. It is engaged regularly every year on such works as road maintenance, clearing fire lines, fire protection operations, etc.

(ii) *Imported labour* may come and live in the forest for one season, or possibly more, but never permanently. Such labour is usually employed on felling and conversion of timber and on road and building works.

The Andamans Forest Department employs 4,000 labourers recruited from the mainland—mostly from Bihar—on contract for two years. For extraction works in Himachal Pradesh, some of the skilled labour is often imported from the adjoining State of Uttar Pradesh and *vice versa*.

Forest villages or settlements

Labour in forest villages or settlements is of a permanent nature and is under an obligation to work in the forest whenever required. The settlements are located at selected centres in the forests and the labour is readily available at all times. These settlements are thus invaluable for the timely execution of many forest opperations. Where taungya plantations are raised, the labour can move to and cultivate in successive taungya centres, but the labourers are usually also allotted small extents of land for

permanent cultivation to induce them to stay on in the forest. Various amenities, such as free housing or materials for house building, educational, medical and recreational facilities, etc., are also provided in these settlements.

Wages

It is essential to pay labour a fair wage, whether it be for daily labour or for piece-work. Underpaid labour will be disgruntled and will finally go away, while overpayment to labour will lead to pecuniary loss. The level of wages will be regulated by the corresponding level obtaining in the adjoining villages from where the labour supply has to be drawn. Local circumstances, such as unusually difficult living conditions and the cost of food supplies, have all to be taken into consideration in deciding on a fair wage. The degree of skill required has also to be gauged, as it is clear that men who are really skilled in a special line of work deserve better wages than those who do purely manual work.

Forest works are carried out either under the direct supervision of departmental staff or through the agency of contractors. In the former case the department pays the wages directly to the labour employed, and the payment is made either (a) by daily labour (on muster roll), or (b) by piece-work.

(*a*) *Payment by daily labour (on muster roll)*.—This is specially necessary where the work has to be carried out carefully under the supervision of the forest staff and cannot be hurried over, e.g., planting, weeding and cleaning, soil working, marking for thining or main felling, etc. A muster roll is maintained of workmen employed and payment is made at rates per day agreed to in advance. There is no special inducement to hard work, and so the workmen require to be kept under constant supervision and made to work for a certain number of hours daily.

(*b*) *Payment by piece-work*.—Here the payment is made on the quantity of work, irrespective of the time taken to do it. It has, therefore, every inducement to hard work. It is the usual mode of payment in vogue for the many forest operations which for one reason or another, cannot be effectively or conveniently supervised, e.g., seed collection, extraction of timber, road and building works. The payment is made on the quantity of work done at rates agreed upon in advance, or specified in an approved schedule of rates, for different items of work. Naturally, payment can be made only after measuring the actual work done and computing the quantities of different items of work. The quality of work should be examined at each stage and it is usual to fix a rigid specification for each item of work.

Larger works are usually executed through the agency of contractors. Supervison is then necessary at all stages to ensure that the terms of the contract are carried out and that the work is up to the required specification. In this case, the department makes the payment to the contractors at rates specified in the contract agreement, and the contractors pay the labour engaged by them.

Supervision

The actual outturn of work and its quality depend, to a very large extent, on the closeness of supervision exercised by the forest subordinates in charge of the work. Personal contact and cordial relations with labour will ensure smooth execution of all forest operations.

Amenities to labour

In recent years, increasing attention is being devoted to the provision of amenities to forest labour. These include : the provision of housing and water supply; the establishment of schools for the education of children; mobile dispensaries for medical treatment; and free transport to and from place of work. In some cases the workmen are also provided with radios, newspapers, magazines, and sports equipment. In a Welfare State, with social welfare and social justice in the forefront of its many ideals, the labour force should be made to feel happy and contented. The expenditure on provision of amenities to labour will more than repay itself through increased all-round efficiency.

Forest labourers' co-operative societies

In some States, such as Madras, Maharashtra and West Bengal, forest labourers' co-operative societies have been organisd with the object that these societies may themselves take over forest coupes on lease and work them through the agency of their members. This procedure eliminates contractors and benefits the labourers appreciably by securing for them fair wages, improved tools and working conditions, and a share in the profits at the end.

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In Madras State, the lease amounts for the coupes are fixed by negotiation and are usually based on the average auction prices realised during the previous three years. In Maharashtra, forest labourers' co-operative societies were organised for the first time in 1947. These societies have proved very popular as may be judged from the fact that from 10 societies in 1947-48 the number rose to 280 in 1965. Forest coupes are allotted to these societies on reasonable terms. Various social service organisations are recognised as sponsoring agencies for the promotion and guidance of the societies. After the registration of society, as per rules, its area of operation is specified and it is allotted timber and fuel coupes, minor forest produce farms, etc. The profits are shared according to certain formulae which are revised from time to time in the light of experience gained. The societies are entitled to the operational costs, a reasonable profit as a percentage of the sale price and certain contribution for carrying out welfare activities for the benefit of forest labour. The working funds required for the exploitation of coupes, etc., are provided to them on easy terms by way of a low rate of interest and a resonable period of repayment. In cases where the financial position of the societies is not strong enough for taking up the working of valuable timber coupes, logging contracts are offered to the societies. In such contracts the responsibility of the societies is limited to felling, conversion and transport of the timber to the sales depots of the forest department. The sale of the material and the subsequent recovery of the sale proceeds are the responsibilities of the forest department. The main advantage of this system is that the funds required are not as large as they would otherwise be: The societies get operational costs, 10 per cent of these costs as profit, and a further 1 per cent as welfare charges. In West Bengal, forest labourers' co-operative socities are also provided with land to enable the labourers to supplement their income from forest work by cultivation.

PART II

WOOD STRUCTURE AND THE PROPERTIES OF WOOD

CHAPTER VIII

ANATOMICAL STRUCTURE OF WOOD

What is wood and how it is formed

Efficient utilization of timber is not possible without a knowledge of the anatomical structure of wood. The latter not only determines to a large extent the properties of wood but also provides the only reliable means of its correct identification. In other words, study of wood structure is very important as it enables one to know and understand the vagaries of this versatile raw material and make the best possible use of it. For a proper understanding of the anatomical structure of wood and its bearing on timber utilization, it is necessary to know what wood is and how it is actually produced in nature.

Wood, as is well-known, has been used since time immemorial, practically since the dawn of man, when our early ancestors roaming the icy wilderness first learnt to use it for fire, shelter and defence against wild beasts and enemies. It is also common knowledge that wood is of plant origin. But, do all plants produce wood and is it all of commercial importance ? The answer to both these questions is in the negative. Lower plants like algae, fungi, mosses and liverworts do not produce any wood at all. It is mainly the product of certain higher groups of plants, namely, the phanerogams or seed plants, comprising the Gymnosperms which include the conifers or needle-leaved trees, the Dicotyledons consisting of broad-leaved species and the Monocotyledons like palms, bamboos and canes. Wood is also produced by some of the higher spore-plants or Cryptogams like ferns and their allies. However, the wood produced by these different groups of plants is not all useful and of commercial importance. If wood is to be commercially valuable and economically exploitable, it should, as in trees, reach a certain useful size. Wood produced by small flowering plants such as twiners, shrubs, etc., has no timber value. Thus, though we have in our country over 15,000 flowering plants and ferns which produce wood in the botanical sense of the term, only about 1,600 or so may be considered as potentially capable of yielding timber or wood of commercial value.

Let us now try to obtain some idea of how wood is produced in a tree. A tree consists of three main parts, namely, the root system, the main trunk or bole which with its branches provides the bulk of wood, and the leafy crown. The roots not only anchor the tree, but also serve to absorb water and mineral nutrients from the soil, which are carried to the leaves through the outer portion of the woody trunk. The green leaves of the crown constitute, as it were, a vast laboratory where the water and minerals from the soil and the carbon dioxide from the air are converted in the presence of sunlight into usable food material required for the growth of the tree. The elaborated food material from the leaves, which consists chiefly of carbohydrates, is conducted through the inner or living bark to the growing regions of the tree—namely, (1) the buds or growing points situated at the tips of shoots and (2) a thin continuous layer of meristematic tissue extending throughout between the bark and wood known as cambium. As a result of the activity of these growing regions, a tree grows or increases in size in two ways. The first, known as primary, apical or height growth, is confined to the buds; and the second, termed secondary, radial or cambial growth, is due to the activity of the cambium. The cambium is a zone of actively dividing cells which, during the growing season, cuts off new cells both externally and internally. The cells which are cut off on the inside go to form the wood, while those cut off on the outside constitute the bark. As a rule, fewer cells are cut off on the outside than on the inside, so that the amount of bark produced in any given period is very much less than the wood. Year after year, the cambium adds more and more woody tissues on the inside and also some bark on the outside, and the tree consequently increases in girth. The amount of wood produced in a growing season depends upon a number of factors like species, climate, environment, etc. In some fast-growing species like balsa (*Ochroma pyramidale*), under favourable conditions, as much as 2.5 cm of wood may be produced all round, during a single growth season.

Gross features of wood

Structural features of wood that can be easily seen with the unaided eye may be considered as gross features. Many of these can best be studied on the cut end surface of a log or on the stump of a newly felled tree (Fig. VIII—1). Outermost is the bark surrounding a central cylinder of wood with the pith in middle.

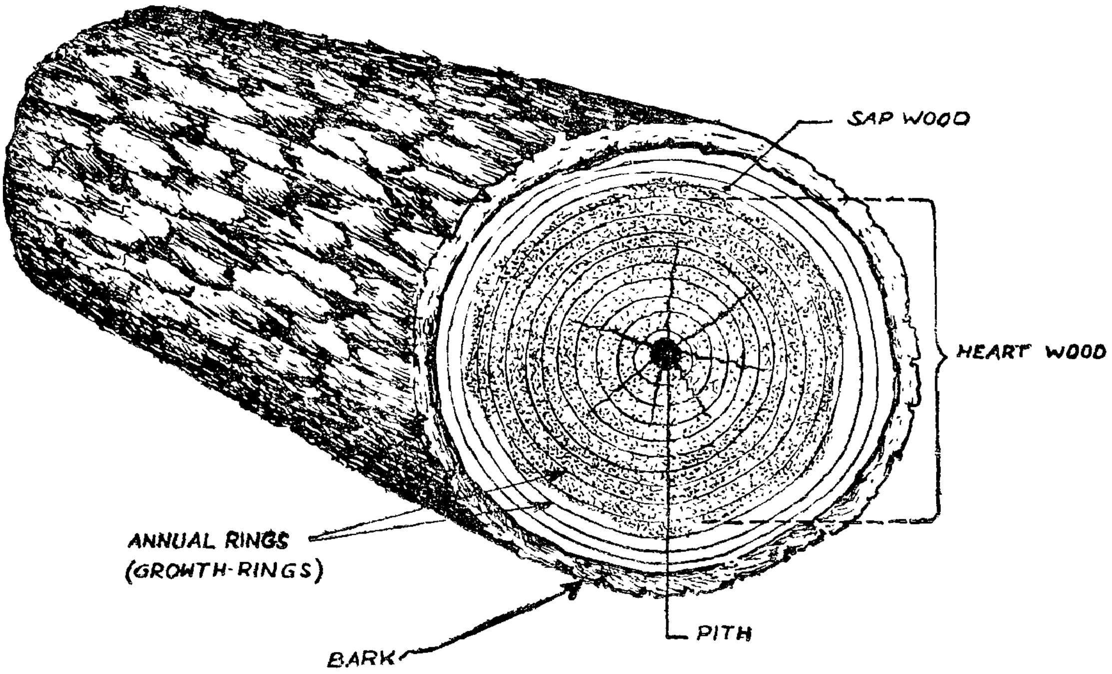

Fig. VIII—1. Cross-section of a log showing gross features.

Bark.—The bark varies in thickness, colour and appearance in different species. It usually shows two distinct regions : an outer protective zone of corky nature consisting of dead and dying cells, and an inner living portion which is actively associated with conduction and storage of food materials required for growth. The outer bark may be smooth, as in *Ficus*, or it may show fissures or cracks, as in *Shorea*. Sometimes the general appearance of the external bark due to fissuring or exfoliation may be so distinctive as to be of some diagnostic value in the identification of trees or logs. Similarly, the nature of the blaze may also be of help in identification, particularly in standing trees.

Pith.—Pith is the soft core found near about the centre of the log. It may be round, oval, triangular or squarish in shape and is usually not more than 0.6 cm in diameter. The colour is commonly some shade of brown, though in some trees it may be pinkish, greyish or yellowish. Unlike the bark and wood, the pith does not seem to have any specific function to perform in the mature tree. It is also not of much diagnostic value, though occasionally it may be very characteritic, as in *Juglans* where it is chambered. The squarish pith with concave sides is also typical of teak (*Tectona grandis*). Usually twigs and young stems have a proportionately larger pith than that found in mature trees.

Sapwood and heartwood.—The woody cylinder shows, as a rule, two well-marked zones : an outer, lighter-coloured portion known as 'sapwood', and an inner or central darker-coloured portion known as 'heartwood'. Colour distinction, however, is not always a true criterion. For example, in the Himalayan silver fir (*Abies pindrow*) and spruce (*Picea smithiana*), there is no colour distinction between the heartwood and sapwood, although, physiologically, heartwood is alawys present in mature wood of any tree species. Among broad-leaved species also, some trees like mango (*Mangifera indica*), semul (*Bombax ceiba*) and fig (*Ficus* spp.) do not always show any distinct heartwood, the woody cylinder being more or less of the same colour throughout. Further, darker colour may not always indicate true heartwood. A typical instance is sal (*Shorea robusta*), in which the sapwood next to the heartwood very often differs from the outer sapwood in having a reddish colour similar to that of the true heartwood. Such darker-coloured sapwood, which appears to be in a transitional stage, is known as *kutcha-pukka* heartwood.

Physiologically, heartwood is dead and does not take any active part in the life of the tree except to give it rigidity. All cells in the heartwood are dead or skeleton cells, consisting of cell walls only without any living contents. The sapwood, however, is composed mostly of living cells and, as its name

implies, is primarily concerned with the conduction of sap. The sapwood is also rich in starch and other food materials and is not durable, being easily attacked by insects and rot in felled trees. Heartwood, on the other hand, is comparatively more durable. For this reason, only heartwood is usually specified for commercial timber, appreciable quantities of sapwood being considered a major defect except where preservative treatment is prescribed. Form an anatomical point of view, however, there is no difference between sapwood and heartwood, though in many cases the heartwood may contain gums, resins, tannin and other extractives, which serve as natural preservatives. They are usually absent, or are not present in the same form, in the sapwood.

Growth rings (*Annual rings*).—Most woods show on the stump or the cut end surface of the logs a number of concentric marks. These may be faint and barely visible, or distinct and prominent to the eye, depending upon the species, and are known as growth marks. The interval between two such consecutive growth marks represents the wood laid down by the tree during a growing season and is commonly referred to as a 'growth ring' or 'annual ring'. The use of the latter term may perhaps be justified in the temperate countries where there is usually a single annual alternation of seasons favourable to growth and the rings provide a reliable index to the age of the tree. In tropical regions, however, as the seasons are not so regular and the rings are not always truly indicative of age, it seems judicious to use the term 'growth ring' instead of 'annual ring'. Many Indian trees like sal, gurjan (*Dipterocarpus* spp.), jaman (*Syzygium* spp.) and mango do not show any distinct annual or seasonal growth rings due to the fact that their intensity of growth is more or less the same throughout the growth season, and one year's growth merges into the next year's growth without any perceptible change. In others, especially conifers like chir (*Pinus roxburghii*), deodar (*Cedrus deodara*), etc., and some of the broad-leaved species like mulberry (*Morus* spp.), teak and toon (*Cedrela toona*), the growth rings are almost always distinct and give a correct idea of the rate of growth. Fast growth is usually indicated by rings wider than 5 to 25 mm, while 8 rings or more per cm of radius are suggestive of slow growth. Width of the growth rings has considerable effect on the strength properties of wood. The occurrence of growth rings and their nature per cm of radius are occasionally also of some diagnostic value. Where the growth rings are distinct and truly annual, the age of the tree may be determined by counting the number of rings.

Early wood and late wood.—Within a growth ring, the wood towards inside, or that formed in the early part of the growth season, is termed 'early wood'. The wood towards the outside, which is laid down in the later part of the season, is known as 'late wood'. Early wood and late wood may differ to a varying extent in structure, texture, or both. Actually the occurrence of growth rings is largely due to the difference between the two. The greater the difference between early wood and late wood the more prominent are the growth rings. For this reason the growth rings, as a rule, are conspicuous in conifers. Within the same growth ring the transition may be gradual as in kail (*Pinus wallichiana*) or abrupt as in chir. In temperate regions, where the early part of the growing season corresponds to spring and the late part to summer, the terms 'spring wood' and 'summer wood' are generally used in place of 'early wood' and 'late wood'.

Grain and texture.—These are two common features of wood which, however, are not so pronounced as the features described above on the end surface of a log. However, they can easily be studied in the gross in any wood and are, therefore, considered here along with other gross features. The terms 'grain' and 'texture' have often been used loosely in connection with timber, giving rise to much confusion. It is therefore necessary to define and describe them in some detail.

Grain in wood refers only to the general direction or alignment of the cells, and should not be confused with texture which is related primarily to the size of the cells. Depending upon the actual alignment of the wood elements in relation to the axis of the tree or the main axis of the piece, the grain may be described as straight, cross, spiral, interlocked, wavy, and irregular (or wild). Though not of much significance from the point of view of field identification of timbers, the nature of grain vitally affects the strength, seasoning and other properties of timber and as such is of great importance in timber utilization. A particular type of grain may be characteristic of some timbers as, for instance, interlocked grain in sal.

As distinct from grain, texture of wood is determined by the size, proportion and distribution of the various wood elements. Common terms used in describing texture are 'coarse', 'fine', 'even'

and 'uneven'. Among Indian timbers, boxwood (*Buxus* spp.), gardenia (*Gardenia* spp.), sandalwood (*Santalum album*) and haldu (*Adina cordifolia*) are fine-textured woods; while mango, hollock (*Terminalia myriocarpa*) and kokko (*Albizia lebbeck*) are coarse-textured. Though most tropical woods are, as a rule, even-textured, some show appreciable difference in texture in different parts of the same growth ring. This is generally the case in some ring-porous hardwoods like mulberry, ash (*Fraxinus* spp.), toon and teak, and coniferous woods with conspicuous and sharply delimited late wood like chir. Such woods are described as uneven-textured.

Minute structure of wood

Anatomical structure and its importance.—The minute structure of wood can be studied only under a compound microscope. When so examined, wood is seen to be cellular in structure, that is, made up of minute compartments or cells, each with a distinct wall of its own, which consists mostly of cellulose and lignin. When these cells are first formed, either at the growing points or from the cambium, they are all similar in shape and size, with thin walls and living protoplasmic contents. Very soon, as a result of growth, differentiation and cell-wall thickening, they become modified in size, shape and structure according to the function they have to perform. Though man in his ingenuity has found many uses for wood, in nature it has only three main functions, namely, conduction, mechanical support and storage. Depending upon their function and structure, the various types of cells that go to make up wood are classified as vessels, fibres, tracheids, parenchyma, etc. Some of these cellular units can be made out clearly with a hand lens magnifying 8 or 10 times, while others, though individually distinct under a high-power microscope, can only be seen collectively under the lower magnifications that may be obtained with a hand lens. The size, proportion and arrangement of different kinds of wood elements vary in different timbers, giving rise to characteristic patterns as seen under a hand lens. No two woods have exactly the same anatomical structure, and the structural patterns seen on the freshly cut end surfaces constitute, as it were, the finger prints of wood by which the identity of any timber could be established.

Apart from its importance in identification, the Minute cellular structure of wood is responsible for some of its unique properties which serve to distinguish timber from other building materials like steel, bricks and cement concrete. Because of the cavities in the cells, wood is extremely porous, relatively light in weight for its strength, and can therefore be transported and handled at low cost. For the same reason, it is not too hard and can be easily worked into various forms with simple tools and minimum of labour. Because of the cellular structure, nails and screws can be driven into wood without much difficulty—a very desirable and useful property in any building material. Again, on account of the air trapped in the cell cavities, wood is a poor transmitter of heat, sound and electricity, and acts as an efficient insulating material. Among other useful properties related to cellular structure are the ability to hold paint and absorb preservatives, and the ease with which two or more pieces of wood can be glued together.

Though conferring a number of advantages, the minute structure of wood is also responsible for some of its major drawbacks like unequal swelling and shrinkage, twisting and warping, combustibility, and susceptibility to decay and damage due to plant and animal organisms that find a suitable nourishment and breeding ground inside the cells.

The basic properties due to cellular structure are not possesed in an equal degree by all timbers. These properties vary not only from timber to timber but sometimes within the same tree. This is so because the proportion of various types of cells and their size, shape and arrangement are different in different timbers. By studying the minute structure of woods it is, therefore, possible for a wood anotomist to assess their properties and suitability for specific uses. The different types of cells that are found in wood and the various ways in which they are arranged are considered below. The description that follows is essentially based on what is seen with a pocket lens, as detailed microscopic features of wood constitute a separate study by itself, which is beyond the scope of this manual.

Pores or vessels

Vessels are vertical series of cells with open ends placed one above the other, forming a continuous tube, like the sections of a drain pipe, running in the direction of the long axis of the tree. Their function is to conduct sap (water and mineral nutrients) from the soil and roots to the crown

for which they are structurally well adapted. On the longitudinal surfaces or broad faces of timber, the vessels frequently show up as long fine scratches or grooves, especially in coarse-textured woods like kokko and mango. When cut across, they appear on the end surface of wood as small, circular or somewhat oval openings or holes, usually visible to the eye or under a hand lens, and are therefore also known as 'pores'. The occurrence of pores or vessels is a constant feature of all broad-leaved trees, and it is for this reason that the wood of broad leaved species is described as 'porous'. On the other hand, in conifers, vessels or pores are entirely absent and the wood is accordingly classified as 'non-porous' (Fig. VIII-2). In the trade non-porous woods are usually referred to as 'softwoods', while porous woods are known as 'hardwoods'. It should be noted here that the terms 'hardwood' and 'softwood' have no relation to the relative hardness or softness of timber but merely refer to the class of trees which produce them, namely, broadleaved species and conifers.

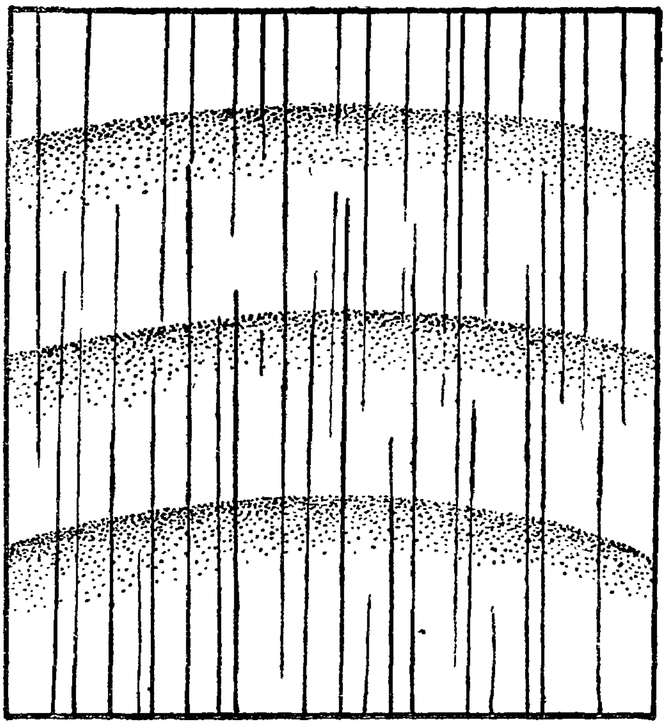

Fig. VIII—2. A non-porous wood (*Abies pindrow*).

Arrangement and size of the pores (Fig. VIII-3, A—F).—Apart from the presence of pores, which is the basis for classification of woods into the two groups mentioned above, the size of the vessels, their frequency, the way they are arranged or grouped and even their contents are of diagnostic value in the identification of hardwoods. Based on the general arrangement of the pores, porous woods can be divided into two main groups, namely, 'ring-porous' and 'diffuse-porous'. In ring porous woods, the pores formed during the early part of the growth season are distinctly larger than those of the late wood and form, as it were, a distinct belt or ring at the beginning of the growth ring. This can be clearly seen in some hardwoods such as teak, mulberry, toon and ash. The majority of Indian hardwoods, however, do not show any appreciable difference in the size of early wood and late wood pores, which are distributed more or less uniformly throughout the growth ring, and are classified as diffuse-porous woods. Typical examples are sal and haldu. The porous may also show various other types of arrangements which may sometimes be very distinctive. In many of the *Ebenanceae* and *Sapotaceae* the pores are usually arranged in long radial chains as in ebony (*Diospyros* spp.) and lambapatti (*Planchonella longipetiolata*), while in some of the *Guttifereae*, like poon (*Calophyllum* spp.) and mesua (*Mesua ferrea*), there is a distinct tendency for oblique grouping of pores. Prominent pore clusters in the late wood are characteristic of many ring-porous woods like mulberry, elm (*Ulmus wallichiana*), celtis (*Celtis australis*) and bakain (*Melia azedarach*). In size also, the pores may show a considerable

range of variation. They may be so minute as to be barely visible even under a hand lens, as in boxwood and gardenia, or so large as to be distinctly visible to the naked eye as in semul or kokko.

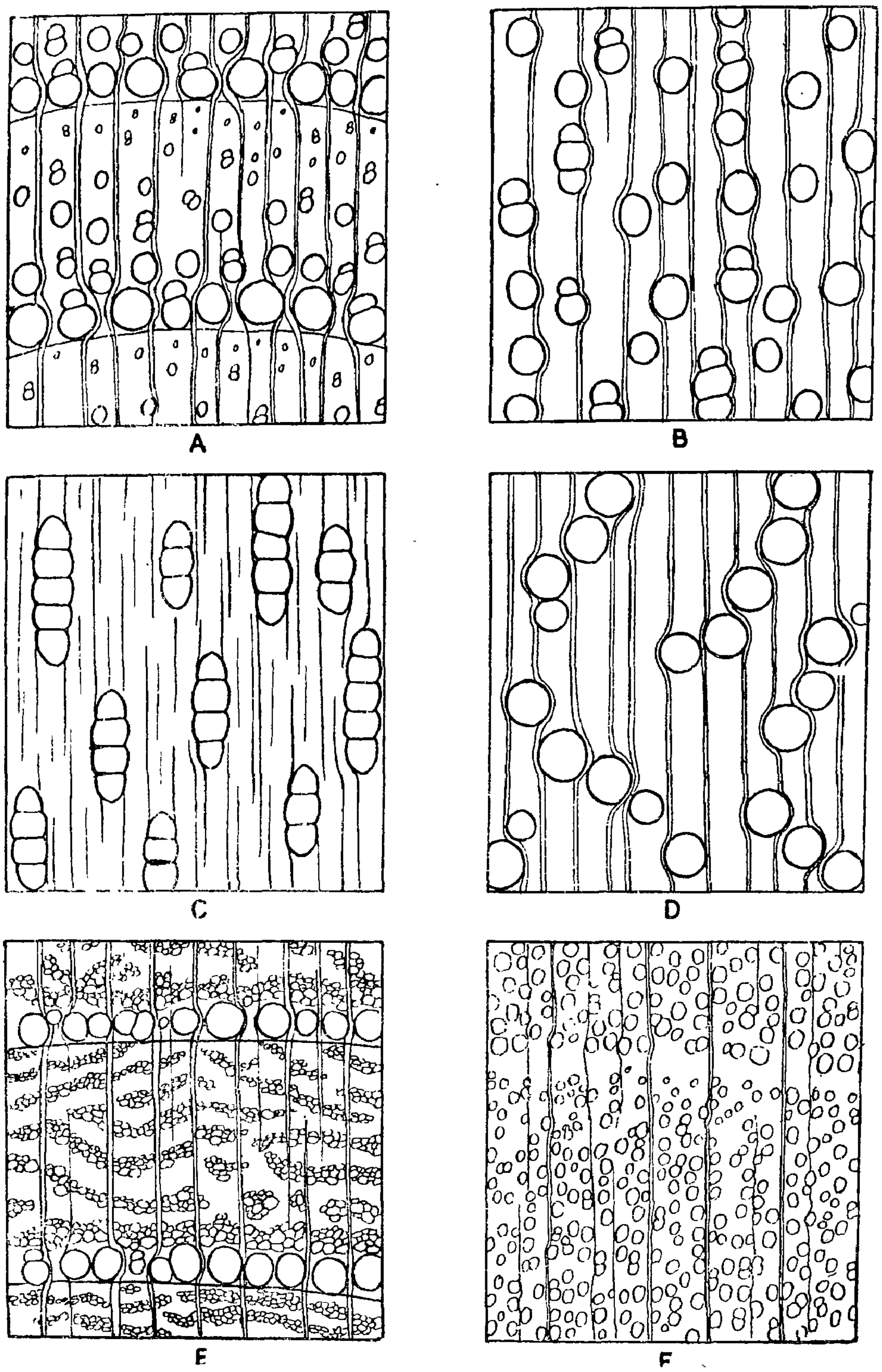

Fig. VIII—3. Arrangement and size of pores.

(A) Ring-porous (B) Diffuse-porous with pores solitary and in short radial multiples
(C) Long radial multiples (D) Oblique groups (E) Late wood pore inclusters
(F) Minute pores.

Tyloses and other inclusions in pores.—In converted timber the pores are, as a rule, open and devoid of contents in the sapwood. In the heartood, however, they may become filled with various deposits and inclusions which are sometimes of considerable importance in identification as well as utilization. The most important among such inclusions are the 'tyloses'. Unlike gums and other chemical deposits, which are mostly infiltration products, tyloses are formed by ingrowths of adjoining parenchyma cells into the pore cavity when the vessels cease to be functional, as during the process of heartwood formation. With a hand lens they appear as glistening foam-like structures, often completely filling the entire pore cavity as in the heartwood of sal. The greater durability of heartwood has often been attributed to tyloses, which control, at least to some extent, the moisture and temperature inside the

wood and thus help to protect it against decay. When present, they are therefore often an indication of durability. At the same time, tyloses offer resistance to the entry and movement of liquids, as a result of which treatment with preservatives and seasoning are rendered more difficult.

Fibres

Fibres are vertically aligned, narrow, elongated and thick-walled cells with pointed tapering ends, which make up the bulk of the wood by weight in most hardwoods. Their main function is to give mechanical support to the tree, and, like the vessels, they are absent in non-porous or coniferous woods. The fibres are individually indistinct even nuder a lens, but collectively they form, as it were, the darker-coloured ground mass in which the vessels and other lighter-coloured wood elements are arranged, giving rise to various patterns.

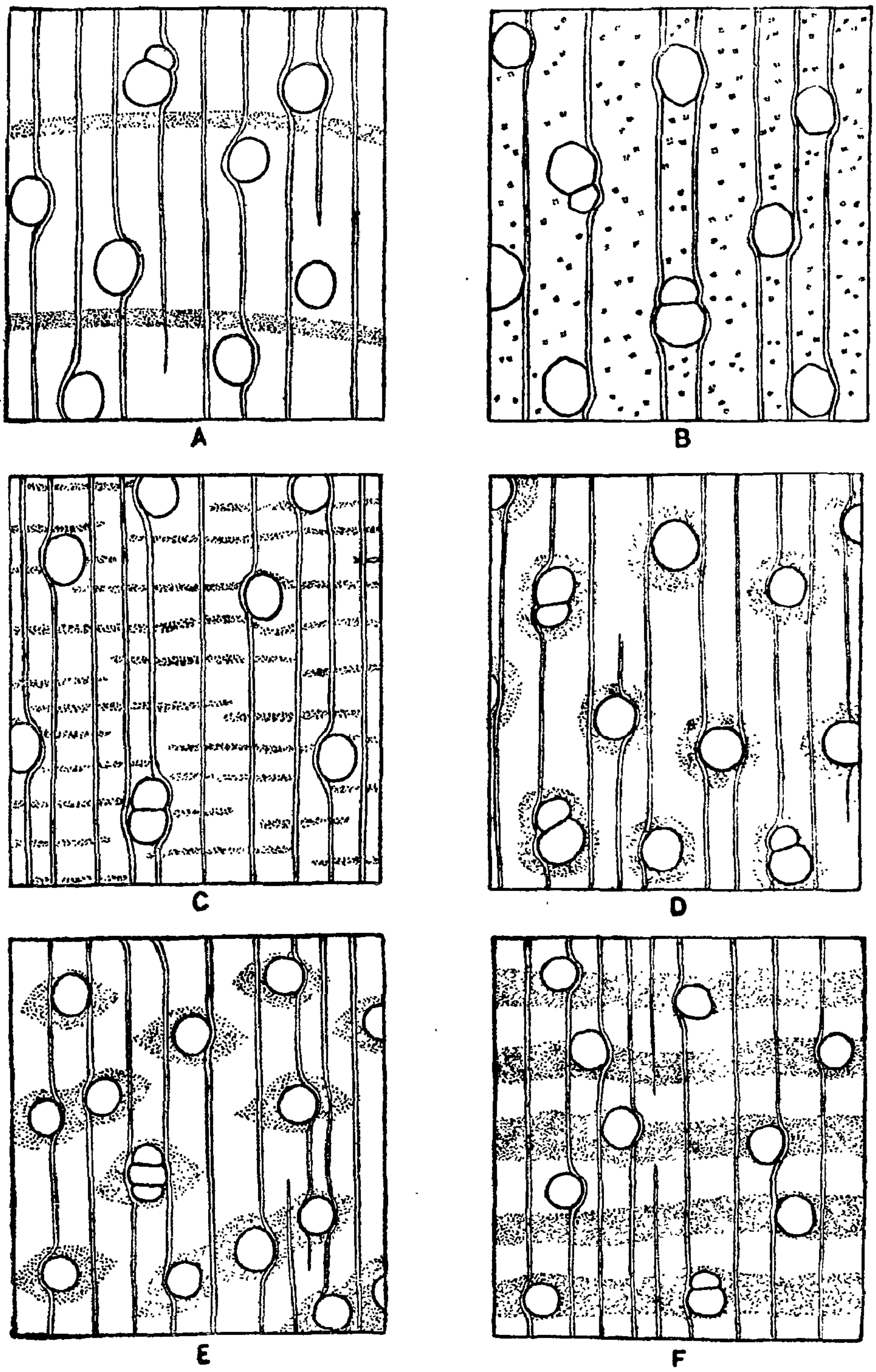

Fig. VIII—4. Parenchyma distribution.

(A) Terminal or initial (B) Diffuses (C) Reticulate or net-like
(D) Vasicentric (E) Aliform and Aliform confluent (F) Banded.

Tracheids

These are the main longitudinal elements of conifers or non-porous woods, in which, as already stated, pores and fibres absent. Their function is to conduct sap and also to give rigidity to the tree. In other words, they combine the functions of vessels as well as fibres of porous woods. Structurally, they are well adapted for this dual role, being well provided with large bordered pits like the vessels but having thick walls and closed tapering ends like fibres. Though as a rule considerably longer and somewhat wider than the fibres, they are individually indistinct under a hand lens and their minute structure can be studied only under a microscope. However, the tracheids formed in the later part of the growing season have very much thicker walls than those of the early wood, so that the late wood in conifers usually appears as a darker, denser and more compact zone, which is sharply delimited from the early wood, thus giving rise to prominent growth rings. The early wood tracheids, with their thinner walls, larger lumen and more abundant pitting are better adapted for conduction, while the denser late wood serves primarily for giving mechanical support.

Wood parenchyma or soft tissues

These are short, rectangular or brick-shaped cells, with comparatively thin walls and simple pits, whose function is storage and conduction and food material. They are oriented in the same direction as fibres and vessels, with their long axis parallel to the grain. Therefore, sometimes they also referred to as longitudinal parenchyma to distinguish them from the parenchyma cells of the rays, (to be described later), which are arranged horizontally. They are found in both porous and non-porous woods, though as a rule they are very scanty or poorly developed in the latter. Individually the longitudinal parenchyma cells are too small to be seen under a hand lens, but collectively they form various patterns which are often very distinctive and of considerable importance in the classification and identification of timber. Some of the more important types of parenchyma distribution (Fig. VIII-4, A-F) commonly met with are described below under two classes, viz., (a) apotracheal and (b) paratracheal.

(a) Apotracheal types. These are independent of the distribution of the pores :

Terminal or initial.—In some hardwoods, the parenchyma cells are arranged in a continuous line or narrow band, which may be formed either at the beginning or at the end of the growth season. Such bands of soft tissue, which are usually lighter coloured than the background, are classified as 'initial' or 'terminal', depending upon when they are formed, and as a rule clearly demarcate or delimit the growth rings. When well developed, they are clearly visible to the naked eye as in champ (*Michelia champaca*) and satinwood (*Chloroxylon swietenia*), while in others, like laurel (*Terminalia tomentosa*), they may be very fine and visible only under a lens.

Diffuse.—When soft tissues occur as isolated cells or small groups of 2-3 cells scattered throughout the ground mass of the wood, the arrangement is described as 'diffuse'. This pattern is often rather difficult to make out under a hand lens, though in some timbers, like dillenia (*Dillenia* spp) and haldu, the trained eye may be able to detect the scattered parenchyma cells as light-coloured dots. In cypress (*Cupressus torulosa*), however, the diffuse parenchyma appears as dark-coloured dots as it contains resin.

Reticulate or net-like.—In some woods the perenchyma cells, instead of being scattered, may form fine, more or less evenly spaced, tangential lines, which together with the rays give rise to a characteristic pattern somewhat resembling the meshes of a net. Such a distribution is described as 'reticulate', or 'net-like' and is clearly seen under a hand lens as in ebony and pali (*Palaquium* spp.). The parenchyma lines may be broken or continuous, closely to somewhat widely-spaced and of varying thickness, giving rise to further variations in the reticulate pattern.

(b) Paratracheal types.—In these soft tissues are closely associated with the vessels :

Vasicentric.—Here the soft tissues form a narrow but complete sheath, more or less of uniform thickness all round, surrounding the pores. Usually the parenchyma sheath is distinctly visible under lens, appearing as a light-coloured border or halo round the pores as in babul (*Acacia nilotica* syn. *A. arabica*).

Aliform or eyelet type.—The parenchyma surrounding the pores, instead of being uniformly thick and narrow, may extend sideways as wing-like lateral extensions. Such a distribution of parenchyma round the pores is described as 'aliform' or 'eyelet' type, and is characteristic of some woods like kokko,

mundani (*Acrocarpus fraxinifolius*) and mango. Not infrequently, aliform and vasicentric types may be found in the same timber. A further development of the aliform type, in which the wing-like extensions of adjacent pores become confluent or connected together, is known as 'aliform confluent'. This type may be seen in sissoo (*Dalbergia sissoo*) and sandan (*Ougeinia oojeinensis*).

Banded.—When soft tissues are arranged in continuous tangential bands, alternating with fibre layers throughout the growth ring, they are described as 'banded'. The bands may be relatively broad or narrow, straight or wavy, and confluent or independent of the pores. Banded structure is conspicuous in palas (*Butea monosperma*), fig (*Ficus* spp.), and narikel (*Pterygota alata*).

The arrangement of prenchyma may not always be as well-marked and distinctive as in the various timbers given above as typical illustration of each type. Further, more than one type may occur and intergrade in the same wood.

Pith flecks

Certain timbers may often show irregular batches of soft tissue, which seem to have no relation whatsoever to the general arrangement of parencyma. These abnormal patches of parenchyma are formed as a result of injury to the cambium due to insect attack, and are known as 'pith flecks'. On the board face, they show up clearly against the natural colour of the wood, but do not constitute a serious defect unless of very large size and numberous. Some species may be more liable to form pith flecks than others.

Rays

Rays are groups or plate of horizonatally-oriented parenchyma cells, which run in a radial direction from the pith or centre of the log towards the bark or periphery. On the cut end of a l og, they appear as light-coloured lines radiating from the centre. Some of them extend from the pith and are known as primary rays, while others which arise at various distances from the pith in between the primary rays are termed secondary rays. Under a hand lens, the rays are as a rule very distinct on the cut end surface of any piece of wood and sometimes may be visible even to the unaided eye. On the tangential surface of the wood, the rays appear as well defined spindle-shaped bodies, somewat darker than the back-ground, while on the radial surface they look like ribbons running across the grain, often somewhat lustrous, The rays show considerable variation in size in different timbers. They may be broad, high and conspicuous to the naked eye or narrow and low, appearing very fine even under a hand lens. Sometimes both the types may occur in the same wood. Broad, high rays are characteristic of oak (*Quercus* spp.) and beech (*Fagus* spp.) and provide an easy means for their identification. Such rays are also responsible for the effect known 'as silver grain' which is produced when some timbers like oak and maniawga (*Carallia* spp.) are quarter-sawn. Fine inconspicuous rays are a constant feature of all conifers and many hardwoods like laurel, benteak (*Lagerstroemia lanceolata*), *and* and ebony.

Ripple marks

Some woods show, when viewed from the tangential surface, a series of fine, equidistant, wavy lines or striations running at right angles to the grain. On account of their resemblance to ripple-like markings on sand caused by the action of wind or water, they are known as 'ripple marks'. They arise largely from rays of more or less uniform height arranged in horizontal rows or series, and are clearly seen in bijasal (*Pterocarpus marsupium*), kanju (*Holoptelea integrifolia*), and satinwood (*Chloroxylon swietenia*). Sometimes one or more of the vertical elements, like longitudinal parenchyma and fibres, may also show a corresponding horizontal striation along with the rays, making the ripple marks very conspicuous. The presence or absence of ripple marks is thus quite often a useful character for identification of timbers.

Intercellular canals (Resin canals or gum ducts)

Intercellular canals are long tubular cavities found in wood, which serve as repositories for waste products of metabolic activity like resins and gums. They are, therefore, commonly referred to as 'resin canals' or 'gum ducts'. They may run either vertically or in the horizontal direction and are found in both porous and non-porous woods. The vertical canals can be distinguished from the vessels by the fact that they are fewer and have no walls of their own. The horizontal canals are similar to the vertical ones but run in a horizontal manner through the rays. In hardwoods, vertical gum canals or ducts occur only in a few timbers and are therefore of great diagnostic value, especially as they are distinctly visible

under a lens, and show different types of arrangements. Predominantly solitary and scattered canals filled with white resinous deposits are characteristic of vellapine (*Vateria indica*), while short tangential groups are typical of gurjan. In sal and hopea (*Hopea* spp), the intercellular canals are arranged in long tangential bands, somewhat resembling growth marks. Radial or horizontal canals are as a rule somewhat smaller and less distinct than the vertical ones, but with some experience they can be made out on the tangential surface of the wood as small reddish or brownish-black circular openings in the middle of some of the rays. They are characteristic of many members of the *Anacardiaceae and Burseraceae* and may be seen in red dhup (*Parishiainsignis*), jhingan (*Lannea coromandelica*) and salai (*Boswellia serrata*). In contifers or non-porous woods also, the vertical canals, when present, show the same type of arrangements as in hardwoods. For example, in chir, kail and spruce they are scattered, while in deodar they are arranged tangential bands of varying length. In fir and cypress resin canals are entirely absent. The horizontal canals in conifers are invariably too small to be visible under a hand lens.

The anatomical features described above afford the only reliable basis for field identification of timber. Some physical properties like weight, hardness, colour, odour, etc. may, in a few cases, be of some help as supplementary aids, but they have to be used with caution.

REFERENCES

Anon	1964	Multilingual glossary of terms used in Wood Anatomy. Zurich, (Committee on Nomenclature, International Association of Wood Anatomists 1964).
Brown, H. P.	1925	An Elementary Manual of Indian Wood Technology; Central Publication Branch, Calcutta.
Chowdhury, K. A. & Ghosh, S.S.	1958	Indian Woods, Vol. 1; Manager of Publications, Delhi.
Desch, H. E.	1968	Timber, its structure and properties; Macmillan & Co., London.
Jane, F. W.	1956	The Structure of Wood; Adam and Chatles Black., London.
Panshin, A. J. & De Zeduw, Carl	1964	Textbook of Wood Technology. Vol. 1: McGraw-Hill Book Company; New York.
Pearson, R. S. & Brown, H. P.	1932	The Commercial Timbers of India, Vol. I & II; Govt. of India, Central Publication Branch, Calcutta.
Tsoumis, George	1968	Wood as raw material; Pergamon Press, Oxford.

CHAPTER IX

PHYSICAL PROPERTIES OF WOOD

Introduction

The term "physical properties of wood" is generally ascribed to denote such inherent qualities as the appearance, colour, density, etc., of wood as also its reaction of sound, heat, light, electricity, etc. They are distinct from the properties which become manifest under the influence of external mechanical forces or chemical reactions. These physical properties have sometimes been predominantly responsible for the numerous uses of wood, such as for musical instruments, decorative surfaces, insulating media, etc. Hence a study of these aspects has been found to be of great value in the economic utilization of various species.

Weight and density

The density of any material is defined as the weight of a unit volume of the material and is expressed as kg/cu m (or lb/cu ft). The "relative density" of a material, also known as "specific gravity", is the ratio of the weight of the material to the weight of an equal volume of water at 4°C. It may be noted that water weighs 1,000 kg/cu m. or 1 gm/cu cm at the above temperature and is equivalent to 62,355 lb/cu ft.

The weight of wood is the sum of the weights of ; (i) the wood substance; (ii) extraneous matter, consisting of mineral and non-mineral substances, contained in it; and (iii) the water present.

While the amount of water in a piece of wood varies according to its "green" or "dry" condition, the other two ingredients in it remain more or less constant. Consequently, for all purposes the standard specific gravity is expressed on the "moisutre-free" basis, otherwise also known as "oven-dry" basis. The oven-dry weight is defined as the weight obtained by drying the wood in an oven, set at an approximately constant temperature of 102°C±1°C, for such time as is needed to make its weight constant. In the usual laboratory tests, with a "moisture-disc" of 2.5 cm length and 5 cm×5 cm cross-section, the approximate time required to obtain the constant weight is 48 hours. If 'W_o' be the weight of oven-dry wood and 'V_g' its volume in green condition (usually obtained by weight of an equivalent volume of water), then the "standard" specific gravity 'S' is given by the equation :

$$S = \frac{W_o}{V_g}$$

When the weight of the wood (W_m) at any moisture content 'm' known, the oven-dry weight 'W_o' can be calculated by the equation :

$$W_o = \frac{W_m}{1 + \frac{m}{100}}$$

The above two formulae can be used for determining any one of the five quantities when the other four are known. 'V_g' is usually determined by immersion method, evaluating the loss in weight of the piece when weighed in air and in water.

Variations in specific gravity.—There are in use various confusing terms pertaining to specific gravity, and therefore the terminology in use is discussed below to help a clear understanding. Principally the weight and volume of a piece of wood can be determined under three different conditions, viz. (1) the "oven-dry" condition which is moisture-free and denoted by a suffix symbol 'o', (2) the "air-dry" condition at a given moisture denoted by a suffix symbol 'a', and (3) the 'green' condition at a given moisture denoted by the suffix symbol 'g'. Hence the specific gravity of wood is to be defined in terms of any of the various possible combinations of the above. If 'ρ_{ik}' denotes the specific gravity where 'i' represents the condition under which weight is taken, and 'k' represents the condition under which volume is

taken, then there can be 9 values of specific gravity, depending on which of the symbols 'o', 'a', or 'g' correspond to 'i' and 'k'.

Thus,

ρ_{oo}= Specific gravity based on oven-dry weight and oven-dry volume. This is also determined in the standard tests and denoted as *oven-dry specific gravity.*

ρ_{oa}= Speicfic gravity based on oven-dry weight and air-dry volume at a given moisture content. This is also determined as a routine in many laboratories and reported along with standard strength data. This is invariably known as *air-dry specific gravity.*

ρ_{og}= Specific gravity based on oven-dry weight and volume in green condition. This is known as *standard specific gravity*, and is determined as a routine in all testing laboratories and reported accordingly in various publications of standard strength data.

ρ_{aa}= Specific gravity based on weight as well as volume is air-dry condition. This is determined as a routine in many laboratories while tesing air-dry material but it is not generally reported along with standard data. This is known as *specific gravity at test in the air-dry condition* and is used only for computing 'ρ_{oa} given above.

ρ_{gg}= Specific gravity based on weight as well as volume in "green" condition of the material. Although the volume does not change with moisture content in the green condition, the weight naturally depends on the moisture content. This is also determined as a routine in several laboratories while testing secimens in green condition and is commonly knwon as *specific gravity at test in the green condition.* This is also not reported along with standard strength data but is recorded to evaluate 'ρ_{oa}' given above.

ρ_{ao}, ρ_{ag}, ρ_{go} and ρ_{ga} have no special significance and are not determined. However, for specific purposes, whenever required. they can be evaluated from some of the above given specific gravity values, it volume shrinkages and moisture contents are known.

Importance of weight.—The importance of specific gravity or weight in wood utilization is often reflected in the fact that it is sometimes taken as an indicator of basic strength or load-bearing capacity. It is also reflected in the cost of the material, its handling and transportation. The classification of wood by specific gravity, as generally practised in commercial fields and described by Limaye (1954), is given in Table IX-I.

The methods of determining the specific gravity and moisture content are described in Chapter X "Mechanical Properties of Wood". Speific gravity and weight of important timbers are given in the Table "Standarad physical and mechanical properties of some selected woods", vide Appendix No. I.

Density of wood substance. —The density of perfectly dry wood varies widely, depending upon the air space (cell cavities) present inside the material. The specific gravity of the wood su bstance (cell-wall substance) alone for all the species is ascertained as 1.53. As such, the overall specific gravity of the different species depends upon relative amount of the cell wall and the cell cavity. Advantage of this is taken for manufacturing compressed wood, in which the specific gravity of woods that are normally light is increased so as to enable their use where increased strength is required. Among the other constituents responsible for variation in the specific gravity, the infilration content is an important feature and this comprises both mineral and non-mineral matter. The mineral matter is left as ash when wood is burnt and seldom makes up to more than 2 per cent of the total figure. The non-mineral infiltration, being generally organic in nature, is extractable by benzene, alcohol, etc., and is responsible for the various colours of the heartwood in the different species. This constitutes generally 10 per cent of the dry weight.

Reaction of sound on wood.—The acoustic properties of wood are of importance in selecting suitable species for musical instruments, auditoria and other special types of buildings. There are, however, no standardized methods of determining the various acoustic properties of wood as in the case of its

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TABLE IX-1

Classification	Limits of weight at 12% moisture content		Corresponding limit of standard specific gravity*, i.e., ρ_{wg}	Examples
	lb/cu ft	kg/cu m		
1	2	3	4	5
Very Light	below 20	below 300	below 0.28	1. Bala (*Ochroma pyramidale*) 2. Suji, or dhupi (*Cryptomeria japonica*)
Light	20 to 29	301 to 450	0.28 to 0.42	1. Papita (*Pterocymbium tinctorium*) 2. Alder (*Alnus* spp.) 3. Gokul (*Ailanthus grandis*) 4. White dhup (*Canarium euphyllum, C. strictum*)
Moderately heavy	30 to 39	451 to 600	0.42 to 0.56	1. Walnut (*Juglans regia*) 2. Salai (*Boswellia serrata*) 3. Vellapine (*Vateria indica*)
Heavy	40 to 49	601 to 800	0.56 to 0.70	1. Teak (*Tectona grandis*) 2. Mundani (*Acrocarpus fraxinifolius*) 3. Uriam (*Bischofia javanica*)
Very Heavy	50 to 59	801 to 950	0.70 to 0.85	1. Babul (*Acacia nilotica*, syn. *A. arabica*) 2. Yon (*Anogeissus acuminata*) 3. Bael (*Aegle marmelos*)
Extremely Heavy	60 & above	951 & above	0.85 & bove	1. Oak (*Quercus* spp.) 2. Rohan (*Soymida febrifuga*)

*"Standard specific gravity" is based on weight oven-dry and volume in green condition.

mechanical properties. The properties associated with sound, and determined from time to time by different workers on different species, are the following. Their methods of determining the properties also vary in different cases.

Velocity of sound in wood.—This is found to be related to the elasticity and density of the species in accordance with the formula :

$$V = \sqrt{\frac{E}{\rho}}$$

where V = Velocity of sound in the direction of required axis of symmetry in wood;

E = Modulus of elasticity in that direction; and

ρ = Specific gravity at test.

As the ratio of 'E' to 'ρ' is nearly equal in many species, in terms of the above equation the velocity of the sound should more or less be the same whether the wood is light or heavy. On the other hand, the presence of moisture in wood tends to decrease the speed of sound because the absorbed water reduces the value

of 'E' and increases the value of 'ρ'. The approximate velocity of sound in wood and other materials is given below in Table IX-2 for comparison :

TABLE IX—2

Material and direction		Speed of sound in m/sec.
Wood	(1) Longitudinal direction	4,120
	(2) Radial direction	1,651
	(3) Tangential direction	1,230
Brick		3,604
Aluminium		5,102
Cork		500
Lead		1,227
Steel		4,987
Water 8.9°C		1,435
Air 0°C		332

Absorption and reflection of sound.—When sound energy impinges on any wooden member, some of it is abosorbed and the rest is reflected. The relative proportions absorbed and reflected depend upon the nature of the surface of the wood, the orientation of its fibres and it intrinsic cellular character. There are also other factors such as moisture content, specific gravity, etc., which may affect the extent of reflection of sound. The ratio of the amount of energy absorbed to the total energy impinged is known as *coefficient of sound absorption*. Taking the case of window-opening one foot (30 cm) square in area, since none of the energy is reflected the coefficient is taken as unity. The coefficient of absorption of all other materials if thus measured against the basic absorption coefficient of unity for an open window. Approximate values of coefficients of sound absorption for different materials are given below in Table IX-3 :

TABLE IX—3

Sl. No.	Material	Coefficient of sound absorption
1	Open window	1
2	Heavy carpet	0.25
3	Wall board	0.20
4	Special acoustic boards	0.20—0.90
5	Brick	0.03
6	Wood unvarnished	0.06
7	Wood varnished	0.03

The unit coefficient of sound absorption is known as a 'sabine' and the total absorption 'Q' for any area of the material is the product of coefficient 'k' and the area 'A'. Thus,

$$Q = kA$$

Narayanamurti (1943) studied sound absorption coefficients of various types of indigenous fibreboards and has come to the conclusion that they compare very favourably with many imported products.

Resonance in wood.—Like many other solid objects, wood also vibrates when it is acted upon by periodic forces, which may be either mechanical vibrating forces or sound waves in the surrounding air. The resonant vibrations in wood can be either "longitudinal", or "transverse" or "torsional". These terms may be slightly misleading with reference to grain direction, as they refer only to the direction of motion with reference to the direction of vibrating forces and the geometric axis of the clamped wood sample. Thus a longitudinal vibration may occur along the grain, across the grain or in any direction of the grain between the extreme positions of a bar. Torsional vibrations are those in which the directional displacement of the vibrating elements describe a carcular motion about the long axis of the sample irrespective of its grain direction. Wood resonates at multiples or "harmonics" of the lowest resonant frequ-

ency knwon as "fundamental" or "first harmonic". In general, the amplitude of vibration is greatest at the lowest resonant frequency and decreases with higher harmonics. The resonant frequencies of a piece of wood are dependent not only upon the velocity of sound and the dimensions of the sample but also upon the manner in which the wood is fastened or restrained from being disturbed from its position. The general formula for the fundamental resonant frequency is given by

$$f_r = K \sqrt{\frac{E}{\rho}}$$

where f_r = the fundamental resonant frequency;
E = Young's Modulus in the required direction;
ρ = specific gravity at test; and
K = a factor depending on the nature of vibration and the method in which the sample is held.

In the longitudinal vibration, $K = \frac{1}{2L}$ where 'L' is the length of the wood sample. In the transverse vibration of the cantilever, $K = 0.560 \frac{r}{L^2}$, where 'r' = the radius of gyration and 'L' unclamped free length. In a rectagular beam of depth 'h', the radius of gyration $r = \frac{h}{\sqrt{12}}$ For a wooden beam supported at two points 0.224 of its length from the ends, $K = 3.55 \frac{r}{L^2}$. It should be remembered that, while in the case of longitudinal vibrations the higher harmonics are obtained by multiplying simply by whole numbers, the same is not true in the case transverse vibrations, as the modulus of rigidity and the moment of inertia of all vibrating portions come into play. Thus, from the above discussion it may be seen that the sound frequency with which a piece of wood is expected to resonate depends upon the species, the made of vibration, the dimensions of the material and the manner in which the piece is held. These principles were applied in the design and construction of several musical instruments, even before they were scientifically analysed or any systematic data obtained. In India, some of the common timbers employed in musical instruments are teak (*Tectona grandis*), toon (*Cedrela toona*), sissoo (*Dalbergia sissoo*), mulberry (*Morus* spp.), jaman (*Syzygium cumini*), haldu (*Adina cordifolia*), spruce (*Picea smithiana*), etc. Among other things, uniformity of texture and freedom from growth defects have also been considered as essential requisites for components of musical instruments. Certain special features, such as "curly grain" in maple (*Acer* spp.) or "wavy grain" in red sanders (*Pterocarpus santalinus*), have given to some woods added advantage in their use for musical instruments.

Reaction of light on wood

As with other objects, the various colours we observe on different species of wood represent essentially a phenomenon of reflection of light, the wood absorbing some fraction of the visible spectrum and reflecting the remainder. This is said to be due to many extractable materials present in woods. Sapwood ordinarily contains little infiltration, so it is generally whitish as compared to heartwood. In addition to the infiltration contents of the wood, the reflection of light also depends upon : (a) the degree of smoothness of the surface on which light falls and is reflected; (b) the plane of the surface, that is, whether it is radial, tangential or transverse; (c) the nature of tissues on the surface in comparison with the longitudinal tissues [e. g., the existence of ray flecks in silver oak (*Grevillea robusta*)]; and (d) the surface moisture content.

Not much has been studied on the ligh reflection properties of wood. Employing a spectrophotometer, Moor and Spencer (1948) measured the reflectance of many species. The average per cent reflectance ranged from 66 for white harewood (*Acer pseudoplatanus*) to 12 for Brazillian rosewood (*Dalbergia nigra*). Application of varnish showed a reduction in reflectance of 15 per cent of the original value. These studies are important mostly in the fields of interior decorations, where the light reflecting characteristics of wood panelling, flooring, furniture, etc., come into prominence. To have proper economically significant visual conditions, one should expect a reflection of at least 50 per cent of the incident light on the panels. In India, species like poon (*Calophyllum* spp.), champ (*Michelia* spp.), teon, silver oak, mulberry and gamari (*Gmelina arborea*), etc., are expected to have lighter reflectance compared to other timbers like uriam (*Bischofia javanica*), jhingan (*Lannea coromandelica*), garuga (*Garuga pinnata*), etc.

Other reactions of light rays on wood, besides the colour reflection, are also of some interest. These are *Phosphorescence*, *fluorescence* and *residual luminescence*. No species of wood is by itself phosphorescent, i. e., capable of glowing when placed in darkness. But sometimes the presence of decay organisms, such as the hyphae of some types of fungi (such as *Armilleria mellea*), imparts phosphorescence to wood. This phenomenon has sometimes been termed as "fox-fires" in India. *Cannabis* is reported to exhibit this phenomenon. Powders and decoctions of some species emit rays which are of lower frequency vibration than those of incident light on them. This phenomenon is knwon as *fluorescence*. When ultra-violet light (which is invisible) is impinged on the surface of such species, the reflected light, being of longer wave length and lower frequency, becomes visible to human eye under different colours. In India, species like *Acacia* spp., *Adina cordifolia*, *Albizia lebbeck*, *Cedrela toona*, *Cassi afistula* and *Morus alba* are said to exhibit fluorescence (Krishna & Chowdhury : 1934). *Residual luminescence* in wood is an optical effect quite different from the above. The absorbed light is emitted as a delayed reaction persisting for a long period of time. Tiemann (1947) has shown that some of these emitted rays are not visible to human eye but can be recorded only on photographic plates after careful exposure. Tiemann pointed out that resinous woods show more luminescence than non-resinous ones, and that while the heartwood of pine (*Pinus* spp.) is more sensitive than its sapwood the reverse is true in the case of poplar (*Populus* spp.) and Lignum vitae (*Guacuma officinale*). He has also come to the conclusion that lignin seems to play a more effective role in this phenomenon than any other substance in wood.

Reaction of electricity on wood

It is well known that there are two types of electricity, viz., (i) static electricity, also known as electrostatics, and (ii) dynamic electricity which is characterized by the flow of electric current. The latter is further divided into two fields : (a) direct current and (b) alternating current. The former type of current flows only in one direction, viz., from the positive to the negative side, but the latter flows alternatively in both the directions. It is, therefore, interesting to consider the behaviour of wood in relation to electricity separately for each of the categories mentioned above.

Direct current properties of wood.—The most significant property of wood with respect to direct current is its resistance to the passage of the current. The electrical resistance in ohms of a unit cubic centimetre of wood is known as its *electrical resisitivity*. Its unit is given by 'ohm-cm'. Expressed mathematically :

$$r = R \times \frac{A}{D};$$

Where, r = Resistivity in ohm-cm;

R = Resistance in ohms;

A = Cross sectional area in sq cm; and

D = Distance between electrodes., i.e., the length of the materials in cm.

Conductivity is the reciprocal of resistivity and is evaluated in units of "mhos" per centimetre.

There are many factors which influence the direct current resistivity and these are discussed briefly in the succeeding paragraphs.

(1) *Moisture content.*—Stamm (1929) has shown that below the fibre-saturation point a linear relationship exists between the logarithm of electrical conductivity (reciprocal of resistivity, 'r') and the percentage of moisture, 'm' in wood. The equation of this relationship is given by :

$$m = 57.5 - 5 \log^{r},$$

$$\text{or } r = 10^{11.5} - 0.2m.$$

Hence completely dry wood is found to be an excellent insulator. Above the 30% level of moisture content the relationship does not remain linear and the effect of change per unit moisture content becomes considerably less pronounced. This principle has been made use of by several workers to determine the fibre-saturation point of various woods. Advantage of this property has also been taken for developing several types of moisture meters.

(2) *Temperature.*—It was observed by Clark and Williams (1933) that a rise in temperature produces a decrease in direct-current resistivity of oven-dry wood. A relationship of the type given below has been suggested.

$$r = \left(10\,(0.8 + \frac{5000}{T}\right)$$

where "T" is the Absolute Temperature (i. e., degrees in centigrade+273). Stamm (1927) has also made similar observations.

(3) *Density.*—No significant influence of the density of wood is reported to be existing on the direct current resistivity of wood. The minor differences observed are atributed to volumes and compositions of the ash contents. However, some observers feel that woods of higher density offer less resistance to the passage of direct current than woods of lower density. (Narayanamurti 1943; Hiruma, J. 1913).

(4) *Grain direction.*—Hiruma (1913) reported that wood shows less resistance along the grain compared to the radial direction. Confirming these findings Stamm (1927) further observed that the longitudinal reistance is nearly half that of tangential or radial, and that the resistance in radial direction is insignificantly less than that in the tangential direction.

(5) *Resin impregnations.*—It has been observed by several experiments that resin impregnated wood shows higher insulating values than untreated woods under the same conditions of exposure and moisture. This property has been made use of for utilising resin-impregnated wood in several types of electrical appliances.

Alternating current properties of wood.—In contrast to the direct current discussed above, alternating current in wood reverses its direction of flow at regular intervals. When the period of reversal is long., i.e., when its frequency is low the general behaviour of wood is more or less the same as that of direct current, but when the frequency increases the properties become strikingly different. The most interesting and useful properties are those exhibited in the range of radio-frequencies, i. e., those of the order of 10 kilo-cycles to 100 megacycles per second. Among the various properties of wood under such frequencies, the dielectric constant, power factor, and radio-frequency resistivity are the most important. The heating of wood by radio-frequency energy is also important from the point of view of drying the wood, or setting the glue-line between different layers of glued laminations. While it is not posssible to discuss all the details in the present chapter, only brief outlines have been made out in the following paragraphs and the reader is recommended to study the "Text book of Wood Technology" by Brown, Panshin and Forsaith, published by McGraw-Hill Book Company, New York.

The *dielectric constant* of wood, also sometimes known as *permittivity* (Hearmon and Burcham, 1954) is defined as the ratio of the capacitance 'C' of a condenser with wood as dielectric medium to its capacitance with vacuum dielectric medium, or

$$\text{(Dielectric constant) } \varepsilon = \frac{C\text{ (wood)}}{C\text{(vacuum)}}$$

While the dielectric constant is principally a property associated with electrostatic condition, i. e., charge and discharge phenomenon, the same principles apply also to radio-frequency range. As in the case of other properties of wood, dielectric constant is also affected by (a) density, (b) moisture content, (c) direction of grain, and (d) frequency of electric current. The lower the density and moisture content, the lower is the dielectric constant. In the case of frequency, however, the lower it is the higher is the dielectric constant. Based on these factors which influence the dielectric constant, moisture-meters have been designed to find out moisture content of timber below the fibre-stauration point and at different frequency ranges. The dielectric constant of oven-dry wood at a density of 0.5 grams per cu cm is approximately 2.0. For woods of other denstities under normal conditions of temperature and humidity, it varies between 3 and 8 in the longitudinal direction for 10 kilocycles to 100 megacycles.

The *power factor* of a dielectric material is defined as the ratio of the electrical energy expended for each cycle in a condenser of the material in question to the total energy stored in the condenser during the cycle. If the energy in charging and discharging is the same, as in the case of vacuum dielectrics,

the power factor is zero. In other materials like wood, molecular and electronic orientations may take place, causing some friction and heat, and so some energy would be required. In terms of frequency 'f', resistivity 'r', and dielectric constant 'ε', the power factor 'P' is given by :

$$P = \frac{1.8 \times 10^{12}}{f r \varepsilon}$$

As in the case of other properties, it is well known that power factor is very much affected by (a) moisture content, (b) density of wood, (c) infiltration products, and also (d) the frequency. The power factor of walnut at 30 megacycles is reported to have increased from 0.03 in the oven-dry condition to 0.13 at a moisture content of 17%. At a frequency of 2 megacycles the power factor of basswood (*Tilia vulgaris*, *T. americana*) is reported to be 0.02 in the oven-dry condition and 0.07 at a moisture content of 16%. The dielectric constants and power factors of some materials are given below in Table IX—4 for comparison.

TABLE IX—4

Dielectric constants and power factors of some common materials under normal conditions

Material	Dielectric constant	Power factor
Vacuum	1.00	0.000
Mica	5—9	0.0001—0.0007
Glass	4.5—7.0	0.002—0.016
Bakelite	4.5—7.5	0.02—0.09
Wood	2—5	0.03—0.07

The resistivity of wood-decreases almost proportionally to the applied frequency, so much so that the low frequency or direct-current resistivity is much higher than the corresponding value at radio-frequencies. At a frequency of 15 megacycles, resistivities are exhibited in the order of 1 megohmcentimetre for wood at 7% moisture content, and the direct-current resistivities for the same condition is found to be of the order of 100,000 megohmcentimetres. This significnt difference is made use of in the radio-frequency heating in glued constructions. As in other cases, moisture content, density, grain angle, and frequency have significant influence on radio-frequency-resistivity of wood.

Reaction of heat on wood

While discussing the reaction of heat on a material like wood the chief properties to be considered are the following :—

1. Thermal expansion, which may be linear in any of the directions of principal axes of symmetry of wood, or areal (Planar) or volumetric.
2. Thermal capacity and specific heat of wood.
3. Thermal conductivity of wood at a steady state.
4. Calorific values of timbers.

Considerable work has been done on wood in relation to heat by several workers in this country and also in other countries, but it is proposed to discuss in the following paragraphs only the broad principles involved in a very brief manner.

Thermal expansion of wood.—When the temperature of any body rises, the internal energy in a given volume of it is also increased; this is accompanied by an increase in the vibration of its molecules and so the average distance between them naturally becomes greater. This is the phenomenon of thermal expansion. But in the case of wood containing moisture, loss of the water under heat tends to shrink the timber. So when measurements of thermal expansions are made on timber the moiture content is usually kept constant within a selected temperature range. The coefficient of linear thermal expansion is defined as increase in unit length for unit temperature rise, and this differs in the three principal axes in wood. In the transverse direction the value is nearly 8 to 12 times of that in the longitudinal direction. However, thermal expansion is much smaller than shrinkage and swelling due to

changes in moisture content, and as such it is usually ignored in designing timber structures. The coefficient of linear expansion is not correlated with the specific gravity of wood, and for various species it is found to range from about 2.0×10^{-6} to 4.0×10^{-6} per degree centigrade in the range of $-50°C$ to $+50°C$. In the longitudinal direction the coefficient is 1/10th to 1/5th of the values for the common metals and other engineering materials.

Thermal capacity and specific heat.—The thermal *capacity* of wood is defined as the quantity of heat required to raise its temperature by the required amount. The *coefficient of thermal capacity* is defined as the quantity of heat required for rising temperature of 1 gm of a substance by one degree. Specific heat of wood is defined as the ratio of the heat required to raise its temperature by a given amount to the amount of heat required to raise the temperature of an equal weight of water by the same amount. Tests have shown that the specific heat of absolutely dry wood increases with rise of temperature, like many other materials, but is independent of specific gravity. It is approximately 0.226 at 0° C, which is practically the same as that of cellulose. The specific heat of cement and aluminium is about two-thirds of that of wood, and for common metals it varies from one-fourth to half of the value of wood. The thermal capacity is measured in calories in the C. G. S. system and in B. T. U. (British Thermal Units) in the F. P. S. system.

Thermal conductivity of wood.—It is well known that dry wood is one of the very poor conductors f heat. This property is eminently suited or using wood for handles of cooking utensils, refrigerators, . The coefficient of thermal conductivity of wood is defined as the quantity of heat which flows in second across unit area of a slab of wood of unit thickness when the temperature of the faces of the el liffers by one degree centigrade. The coefficient of thermal conductivity of wood is given by the la :

cur. i.e., when n

$$Q = \frac{KAT\,(t_2 - t_1)}{d}$$

Where : Q = amount of heat conducted;

K = coefficient of thermal conductivity expressed in the C. G. S. system in calories/sq cm per degree centigrade difference/per second;

A = Area perpendicular to the direction of heat-flow in sq cm;

t_1, t_2 = Temperatures of the cold face and the hot face respectively;

T = time in seconds for which the heat flows and

d = distance between the faces in cm.

As in other cases the thermal conductivity varies with the direction of grain, specific gravity and moisture content. The nature of extractives, proportion of early wood and late wood, and gross physical features such as knots, checks, cross-grain have all been found to influence thermal conductivity.

Combustibility and calorific values of wood.—It is well known that wood is combustible. As such it has served as a domestic and industrial fuel. By combustibility of wood is meant the readiness with which it catches fire and continues to burn until only the ash remains, thus involving also a time factor. But the heating power of wood is the quantity of heat emitted by a given weight of wood during the process of combustion, and is measured in terms of what is called the "calorific value". Atmosphere and such properties of wood as moisture content, specific gravity, porosity, etc., influence its combustibility and heating power. But the factors which influence combustion do not necessarily influence the heating power in the same manner. Hence the overall "fuel value" of wood depends upon the combination of combustibility and heating power, as also such factors as emission of smoke, sparks and objectionable gases.

The calorific value of any substance is quantitatively expressed as the number of heat nuits obtained by complete combustion of unit mass of fuel under specified extraneous conditions, and is expressed in "Gram Calories" or simply "Calories", or in "British Thermal Units/lb." Figures in British Thermal Units can be converted into calories by multiplying by 0.556, and figures in calories can be converted into British Thermal Units by multiplying by 1.80. The calorific value of combustible materials is determined in various ways, but the main principle involved is the measurement of the quantity of heat generated by a unit mass of the combustible substance (which is wood in the present case) under specified

conditions. In other words, the calorific value in C. G. S. units indicates also the number of grams of water that can be raised in temperature by one degree centigrade when one gram of wood is completely burnt. Thus, if the calorific value of a particular species of wood is 5,000 calories, then one gram of that wood under complete combustion will raise the temperature of 5,000 grams of water by 1°C. Similarly if the calorific value of coal is 8,000 calories, then one gram of coal will raise the temperature of 8,000 grams of water by 1° C.

Since different species of wood with the same moisture content are, generally, basically alike in chemical compositions, the calorific values of woods in the air dry condition are about the same, varying only between 4,500 and 5,200. Woods containing combustible extraneous substances like resins, oils, gums, etc., however, show a higher calorific value than others. With a few exceptions, e. g., *Anogeissus pendula, Bischofia javanica*, etc., the heartwood has generally a highr calorific value than the sapwood. The calorific values of several Indian species have been determined by Krishna and Ramaswani (1932). The values for some of the species have been given in Table IX-5 below, along with the values of some other combustible materials for comparison.

TABLE IX—5

Calorific values of different solid fuels

Substance	C. G. S. System (Units : Calories)	F. P. S. System (Units : B.T.U./lb)
Coal	7,875	14,175
Coke	6,900	12,420
Lignite	4,000	7,200
Straw	3,336	6,000
Baggasse (45% m. c.)	4,726	8,500
Deodar (*Cedrus deodara*)	5,294	9,528
Babul (*Acacia nilotica*, syn. *A. arabica*)	4,870	8,765
Casuarina (*Casuarina equisetifolia*)	4,950	8,910
Axlewood (*Anogeissus latifolia*)	4,948	8,900
Sal (*Shorea robusta*)	5,264	9,476
Imli (*Tamarindus indica*)	4,939	8,891
Oak (*Quercus* spp.) (13% m. c.)	3,990	7,182

Permeability of woods to water and other liquids

Penetration by water.—When placed in contact with water or a moist material like soil, dry wood will first absorb moisture. The rate of absorption becomes slower progressively, and the saturation of wood is reached only after a long period. Logs kept in water long enough will eventually absorb sufficient water to fill the cell cavities almost fully,and thus becoming waterlogged will sink in the water. In river transportation, when logs are floated over long distances some loss occurs owing to such sinking of logs by waterlogging during transit. In sleepers of chir (*Pinus roxburghii*), kail (*P. wallichiana*) and deodar (*Cedrus deodara*) floated down the Himalayan streams, such loss rarely exceeds 1 to 2 per cent. Teak (*Tectona grandis*) logs floated down streams in South India do not usually sink.

Sapwood absorbs water more speedily than heartwood. End-grain absorbs water more rapidly than side-grain, and tangential faces more rapidly than radial faces.

Wood-water relationship is discussed in detail in Chapter XII.

Penetration by other liquids.—Many conditions affect the extent of penetration of wood by a liquid. These include : the character of the liquid, the species of wood, sapwood or heartwood, the direction of grain, the moisture content, the temperature and the pressure if any applied and its duration. Woods with large pores are easily penetrated. Those characterized by tyloses resist penetration and are thus prized for tight cooperage. Penetration is always greater along the grain than across the grain. Penetration is more in sapwood than in heartwood. The presence of water in the cavities of the green wood impedes penetration. Aqueous solutions penetrate more easily than

oil and oil-solutions. The treatment of wood with various liquid preservatives is dealt with in Chapter XVI "Wood Preservation".

The extent to which liquids enter wood, either spontaneously or when forced in under pressure, has an important bearing in many fields of wood utilization : impregnation with preservative, fire-retarding and water-proofing materials, staining and polishing, gluing as in plywood and laminated wood, using solvents to remove extraneous substances, etc.

Wood-working qualities

Although wood-working qualities do not come strictly under the usual concepts of physical properties, these qualities have considerable impacts on utilization of various species of timber when viewed alongwith other physical properties mentioned above. In the determination of wood-working qualities the following are generally studied :

1. Relation of a particular timber to machine operations like sawing, planing, boring, mortising, tennoning, machine shaping, turning, etc.
2. Relation of timber to hand operations like filing, hand-sawing, hand planing, chiselling and carving.
3. The behaviour of timber in taking finishes like varnish, wax polish and paints of various kinds.

In this field, no systematic sudies have been made with regard to Indian species nor there are any accepted standards. However, such properties have been qualitatively described by different workers such as H.E. Kinns (1925), Trotter (1929,1941, 1944, 1960), Pearson & Brown (1932), V.D. Limaye (1939), Sekhar, A.C. (1955). Sekhar has made some attempts to standardise the methods of tests for a qualitative desciiption. Further technological studies for quantitative description of these properties have been taken up only recently. In the qualitative description of the wood-working qualities of various species, the following are generally taken into consideration :

(a) The feel on the hand of the worker at the time of sawing or planing, both on machine and by hand.

(b) The display of the machine marks on the surfaces produced in the three principal planes of timber.

(c) The deviation of fibres and existence of chipped portions at the sharp corners of the tested specimen.

(d) The type of wood shavings, whether broken or continuous.

(e) The bluntness of tools and knives that may be observed.

(f) The effort needed for a good finish of the surface and the capacity to retain polishes and paints.

Wood-working qualities have been normally considered useful for such uses of timber like furniture, panelling, ceilings, etc. However, its economic impact is sufficiently significant in the industrial uses of timber where other physical propeties like density, shrinkage, effect of heat and electricity, come into prominence for specific uses such as in the manufacture of rifle components, textile accessories, battery separators, etc. Among Indian woods, that are difficult to work with, mention may be made of mesua (*Mesua ferrea*), Kokko (*Albizia lebbeck*), sal (*Shorea robusta*),etc. Among those which are said to be easy to work with mention may be made of white dhup (*Canarium strictum*), deodar (*Cedrus deodara*), mango (*Mangifera indica*), teak (*Tectona grandis*), etc. Timbers containing extensive resin or oil are unfit for use where polish and paints are required. some timbers like padauk (*Pterocarpus dalbergioides*) and toon (*Cedrela toona*), being very absorbent, require a good deal of "filling" before they can be polished. Timbers like kokko (also known as sneeze-wood), safed siris (*Albizia procera*) and laurel (*Terminalia tomentosa*) produce dust with irritating effects on the nostrils and throats of workmen. Wood-working qualities are also affected by the moisture content, presence of visible defects, like knots, cracks and straightness of grain etc. Chir (*Pinus oxburhii*) and kail (*Pinus wallichiana*) show marked difference in their working properties due to the above defects.

Wood work is usually finished by appropriate staining, polishing and finishing. Wood, ordinarily, takes paint readily. Practical experience shows that paint stays longest on quarter sawn wood and that it

has a comparatively shorter life on flat sawn. The ability of wood to take a high degree of polish determines its usefulness as a cabinet wood.

Wood in relation to other physical properties

Porosity in wood is a measure of the relative size and abundance of cell cavities known as lumen. Woods with thin cell walls and large cell cavities are comparatively more porous, and thus also lighter, than woods with thick walls and small cell cavities. Woods are generally more porous in transverse surface than in radial or tangential surfaces.

Porosity is of particular importance as a determinant of penetration in woods of water and liquids, e.g., in floating logs, painting and preservative treatment of timber.

Colour in wood, though very variable, sometimes helps in identificatin. In spite of similar structure in some materials like teak from India and Burma, their colour is often used for separation in commercial fields. Generally wood darkness on exposure to sun and weather, and this is attributed to the chemical changes that take place on the surface of the material. Teak, mulberry and toon are some examples of woods which change colour rapidly on exposure. Hence it is not always safe to describe a dry timber purely on the basis of its colour. Sometimes there is a great difference in colour between heartwood and sapwood as, for example, in the case of ebony (*Diospyros* spp.) and rosewood (*Dalbergia latifolia*). The difference in colour within and between various species is made use of for producing multi-coloured laminated designs of panels for interior decorations, table-tops and fancy articles, etc. This is deal at with in Chapter XXIII "Decorative uses of Wood".

Some timbers exhibit characteristic *lustre* by reflection of light from the cell walls. The degree of lustre depends upon : (1) cell-wall structure, (2) plane of cut, and (3) angle of incidence of light. Among conifers, spruce (*Picea smithiana*) has a peculiar lustre of its own. Among broad-leaved trees, the quarter-sawn timber of some species shows beautiful lustre, e.g., oaks, chickrassy (*Chukrasia tabularis*), poon, etc.

Many woods exhibit some characteristic *odour* which is sometimes helpful for identification. The odours are generally due to resins, oils and other chemical substances present in the species, and are more prominent in green wood than in seasoned wood. Examples of this may be seen in deodar (*Cedrus deodara*) and pines. Sandalwood (*Santalum album*), some species of *Eucalyptus*, and cedar woods (*Cedrus* spp., *Cedrela* spp. etc.) have peculiar aromatic odours, which are sometimes welcomed for various specific uses and thus enhance the value of these woods in utilization. Some of the chemical components in woods have the property of repelling moths and other insects, e.g., camphor and allied substances in *Cinnamomum camphora*.

Although *taste* is also a separate distinct property of some of the woods, in many cases it is closely related to odour, and the characteristic taste is often traceable to the same constituents as those responsible for the odour. Taste is said to be more pronounced in the heartwood than in the sapwood. Taste as a property is made use of in selecting wood for containers of foods and drinks, ice-cream spoons, etc. This is also sometimes considered for such objects as pencils which are apt to be chewed to some extent, particularly by small school-going children.

It may be seen from the above paragraphs that physical properties have considerable impact on economic utilization of wood, and as such systematic investigations under standardized methods form an essential feature in the various aspects of research conducted in timber utilization.

REFERENCES

1. Clerk, J. D. & Williams J. W.	1933	The Electrical Conductivity of Commercial Dielectrics and its variation with temperature; *Jour. Phys. Chem.* Vol. 37.
2. Hearmon, R. F. S. & Burcham, J. N.	1954	The Dielectric Properties of Wood; Forest Products Research Sepecial Report No 8; Deptt. of Scientific and Industrial Research (London).

3. Hiruma, J. 1913 Experiments on the Electrical Resistance of Wood. Bull. For. Experimental Station, Meguro, Tokyo. Vol. 10.

4. Kinns, H. E. 1925 A Note on the Working Qualities of some common Indian Timbers; Forest Bulletin No. 66 (Economy Series), Govt. of India, Central Pulication Branch, Calcutta.

5. Krishna, S. & Chowdhury, K. A. 1934 Fluorescence in Timbers; *Current Science*; Vol. III, No. 2.

6. Limaye, V. D. 1932 The comparative strength of some important Indian Timbers and their uses; *Indian Forest Records* (New Series) Utilization Vol. 1—A.

7. Limaye, V. D. 1954 Grouping of India Timbers and their properties, uses and suitability; *Indian Forest Records* (N. S.) Vol. 1, No. 2.

8. Moon, P. & Spencer, D.E. 1948 The colour of unstanied woods. J. *Opt. Soc.*, America Vol. 38.

9. Narayanamurti, D. 1943 Thermal Conductivity and other properties of some indigenous materials; *Indian Forest Records* (N. S.), Utilization Vol. 3, No. 2.

10. Pearosn, R. S. & Brown, H. P. 1932 Commericial Timbers of India; Govt. of India, Central Publication Branch Calcutta.

11. Sekhar, A. C. 1955 Working Qualities of Some Indian Timbers; *Indian Forest Bulletin* No. 194 (New Series), Timber Mechanics.

12. Stamm, A. J. 1927 The Electrical Resistance of Wood as a measure of its moisture content; *Ind. & Eng. Chem.* Vol. 19, U. S. A.

13. Stamm, A. J. 1929 Fibre-saturation Point of Wood as obtained from Electrical Conductivity Measurements; *Ind. & Eng. Chem.* Anal. Edit. Vol. 1, U.S.A.

14. Tiemann, H. D. 1947 Residual Luminescence of Wood, *South Lumberman* 175, U. S.A.

15. Trotter, H. 1929 The Common Commercial Timbers of India and their uses. Manager of Publication, Delhi; republished in 1941, 1944 and 1960.

CHAPTER X
MECHANICAL PROPERTIES OF WOOD

Introduction

Mechanical properties of wood are those that indicate the ability of wood to resist various types of external forces, static or dynamic, that may act on it. The type of deformation, whether in size or in shape, caused in wood when it is subjected to an external force, depends on such mechanical properties, as *modulus of elasticity, ultimate stress, fibre stress at elastic limit*, etc., which are inherent in wood. These properties, however, vary not only with species, with reference to the nature of their fibre structure, but also with the moisture content, temperature and defects of the woods subjected to the forces. Even in respect of the same species, the properties vary with reference to the varying conditions of growth and methods of testing. Hence in evaluating the mechanical properties for different species of wood, the methods of testing, the sampling of the specimens for various tests, etc., would naturally require a high degree of standardization, in order that the results obtained may be comparablee as between the species, repectable under the conditions specified, and reliable for use under given circumstances. In the present chapter, a study will be made of the different aspects involved in the determination of mechanical properties, the variations of these properties in timber, and the factors that are relevant, in the context of these properties, to the use of woods for industrial and engineering purposes.

In India, studies on the science of *Timber Mechanics*, which deals primarily with the evaluation of mechanical properties of wood, originated sometime early in the twentieth century when the strength tests of several timbers were reported by W.H. Everett (1906), W.H. James (1916), and J.H.C. Kann (1923). Timber testing, however, was commenced in a systematic way at the Forest Research Institute, Dehra Dun, in 1921, and the first three reports of such work were published by L.N. Seaman (1924), L.N. Seaman and C.R. Ranganathan (1926), and V.D. Limaye and L.N. Seaman (1933). Timber testing was pursued at the Forest Research Institute in a routine manner periodically between 1933 and 1950 ; subsequent reports about the strength properties were brought out by A.C. Sekhar and others (1955-66) in the form of *Indian Forest Records*. Since then the subject has expanded itself into the greater fabric of the *mechanics of materials*. Also, going deep into the fundamental characteristics of wood as a biological material, studies have been made on variations due to inherent growth characteristics, moisture and temperature, the nature of stresses and methods of testing, etc. (Sekhar & Negi : 1961). The knowledge of the effects of defects in timber has opened a new field in grading and new lines of approach in designing. It is now fairly well accepted that wood is an orthotropic, elastoplastic material, with its fundamental mechanical properties varying differently in the three mutually perpendicular directions coinciding with the structural axes of the wood, viz., the longitudinal, radial and tangential directions, as shown in Fig. X-1. These variations have assumed considerable importance in the development of wood products

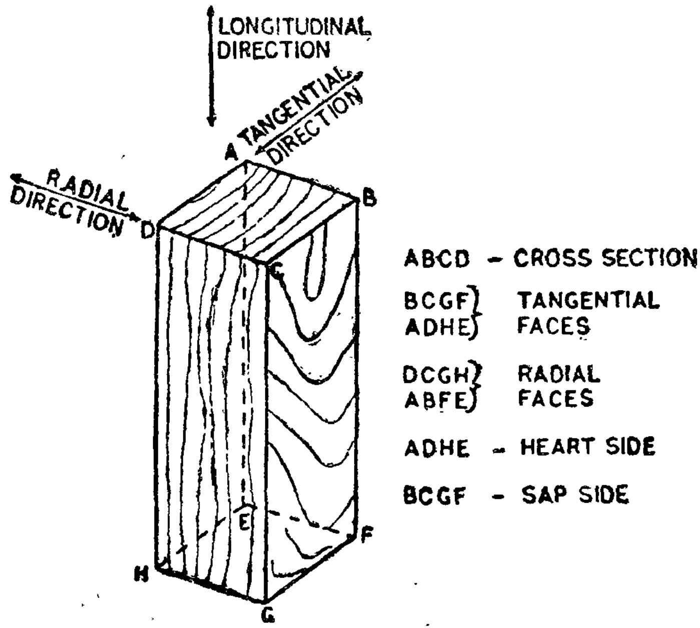

Fig. X-1. Principal directions and surfaces of symmetry in timber.

like plywood, laminated wood, etc. A study of the final failures in wood and their bearing on the inherent nature of timber, such as toughness, brashness, etc., has led to a more appropriate evaluation of the suitability of wood for many industrial uses, such as tool handles, agricultural implements, packing cases, etc. In addition to the above, recent advances also include development in special tests on wood poles, railway sleepers, structural elements, plywood plates, particale boards, doors, bamboos, and canes, etc.

The usual form in which mechanical properties of wood are reported in this country is given in Appendix I, together with the relevant data for ten selected woods in two parts, (A) with standard clear specimens in *green* condition and (B) with standard clear specimens in *air-dry* condition. The different properties are evaluated in accordance with established practices and standards which are discussed later in the section on "Standard tests on Indian timbers".

The properties of many other woods are available in various publications and records of the Forest Research Institute. A study of these properties indicates that they vary widely among the various species. Table No. X-1 shows the maximum and minimum strength values for each of the four genera, based on the data pertaining to several species in each. Similarly, the coefficients of variations of the different properties of timber based on the average values for 50 consignments of wood of each species and each consignment comprising five trees from a locality, have been worked out (Sekhar & Negi: &1959). The average, maximum and minimum values of the coefficients for the different properties are given in Table No. X--2.

Definitions and General Principles

To enable an understanding of the mechanics of timber and the various terms associated with its mechanical properties, certain fundamental considertions relating to the action of forces on a body, and the technical terms applied in the context, have first to be understood. These are dealt with below.

When a body is subjected to a set of forces, it undergoes a change in size, shape or both, depending upon the type of forces, the type of the body, and the manner of appjication of the forces on the body. Under a direct external application of a force on the body, the force acting on a unit area is called *stress* and the deformation per unit measure (of length, area or volume) is known as *strain*. When a graph is drawn for strain against stress, a type of curve as shown in Fig. X-2 is obtained. Beginning as a straight line, the curve later becomes non-linear; it progresses to a maximum and then drops, the latter part indicating fall in stress with increase of strain until there is a complete failure. It may be noted that the curve in the figure is only a general representation and that the same intensity of stress does not produce the same strain in all woods, and even in different pieces of wood of the same species.

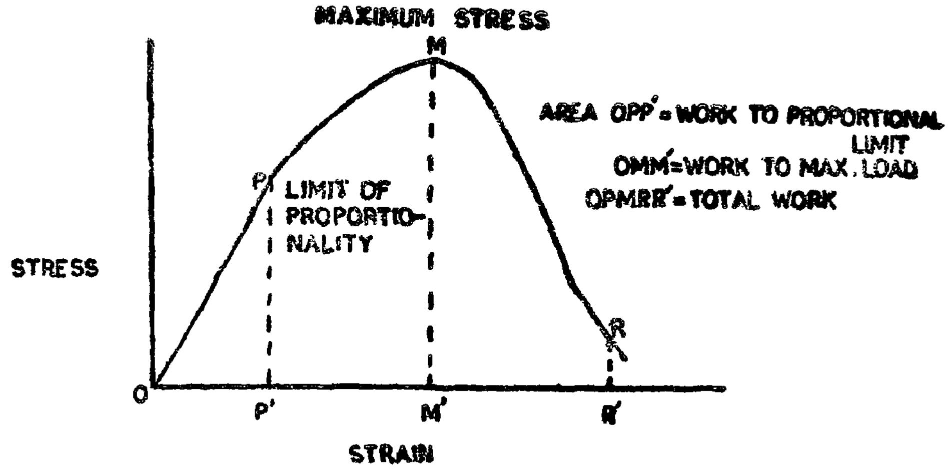

Fig. X—2. Typical Stress-Strain curve.

The point at which the linearity of the curve changes to non-linearity is known as the *Limit of Proportionality*, popularly known as the *Elastic Limit*. It may be seen that below the limit of proportionality the stress is directly proportional to strain. The ratio of stress to strain is known as the *Modulus of Elasticity*. The stress at the limit of proportionality in the case of wood is known as *Fibre Stress at Elastic Limit*, and the stress at the maximum point as the *Maximum Fibre Stress* or, in referring to bending of wood, as the *Modulus of Rupture*. The final point at which the material completely breaks is known as the *Breaking Stress*.

TABLE X--1

Maximum and minimum strength for a genus in green condition

Genera and Species	Specific gravity		Modulus of rupture lbs/sq in. (kg/sq cm)	Max. Cr. Stress in Comp. parallel to grain lbs/sq in. (kg/sq cm)
Pterocarpus spp.				
P. dalbergioides	Max.	0.967	17,800	10,300
P. macrocarpus			(1251)	(724)
P. marsupium	Min.	0.620	10,600	5,200
P. santalinus			(745)	(366)
Lagerstroemia spp.				
L. speciosa	Max.	0.620	10,340	5,310
L. hypoleuca			(724)	(373)
L. lanceolata	Min.	0.504	8,590	4,280
L. parviflora			(604)	(301)
L. tomentosa				
Dipterocarpus spp.				
D. alatus				
D. bourdillonii				
D. grandiflorus				
D. griffithii	Max.	0.726	11,600	5,850
D. indicus			(816)	(412)
D. kerrii	Min.	0.574	8,940	4,430
D. macrocarpus			(629)	(311)
D. tuberculatus				
D. turbinatus				
Terminalia spp.				
T. arjuna				
T. belerica				
T. bialata	Max.	0.796	12,470	6,600
T. chebula			(877)	(464)
T. manii				
T. myriocarpa	Min.	0.508	8,400	4,120
T. paniculata			(591)	(290)
T. procera				
T. pyrifolia				
T. tomentosa				

When a force is applied on a piece of timber in a way that the fibres are pulled apart, the timber said to be subjected to *tensile stresses*. If the force is in the direction of fibres, then it is known as a *longitudinal tensile force;* if it is applied across the fibres it is known as a *lateral tensile force*. In these two cases, the state of strain or stress that exists in the wood is known as *tension parallel to grain* and *tension perpendicular to grain* respectively. Similarly, when the forces are so applied that the opposite ends tend to come closer to each other, there is said to exist a state, as the case may be, of either *compression parallel to grain* or *compression perpendicular to grain* in the material. If the forces are along the fibres, the material is said to be subjected to *longitudinal compressive stresses*, and if they are across the fibres it is said to be under *lateral compressive stresses*.

Similarly, when a material is placed on supports and subjected to lateral forces, known also as bending forces, the layers of the material on the convex side are in a state of tension and those on concave side are in a state of compression. Somewhere in between the concave and convex surfaces, there exists a surface called *neutral surface* on which there are neither tensile forces nor compressive forces. A line passing through the centre of the neutral surface, and parallel to its longitudinal edges, is knon as *neutral axis*. Sometimes, this term is loosely used for expressing the position of the surface of the neutral axis.

When forces are so applied that they tend to cause one part of the material to slide or slip on its adjoining part, the material is said to be in a state of *shear* and shearing stresses are said to act on the material. It may be seen that, when one portion of the material slides over the other portion, it is the area over which the sliding takes place that comes into the picture, the force required per unit of such area is known as *shearing stress*. A shearing stress acting on longitudinal-tangential plane is known as *tangential shear*, and one acting on longitudinal-radial plane as *radial shear*. Shear occurs almost invariably in planes involving the longitudinal directions, and in all such cases it is known as *shear parallel to grain*, but occasionally such terms as *shear perpendicular to grain* and *oblique shear* are also used, depending on whether a radial-tangential plane or any other oblique plane is involved. This type of shear perpendicular to grain and oblique shear occur mostly when timber piece is subjected to lateral twist, also known as *torsion*. Shear perpendicular to grain is also sometimes considered with reference to materials projected beyond the bearing surfaces on which they are supported as, for example, in the case of beams. However, it may be noted at this stage that this type of shear is never responsible for a failure in the material. The type of shear that is responsible for failure in a beam under lateral loading forces is known as *horizontal shear*, and it normally occurs on the neutral surface. Hence this is an important factor in the design of beams.

The term *strength* is used in a broad sense to include all those mechanical properties of wood which describe the stress and strain behaviour discussed above, but, in a limited usage, when different species are to be compared, the concept of strength is restricted to the behaviour of defect-free material of regular shape and size under any of the specific stresses mentioned above. However, when the term is used with reference to any specific size and shape of the material, it refers to the maximum force of a specific type that comes into play on the material. The unqualified use of the term has often led to confusion, and in the strictest sense only that specific property of wood which pertains to a specific use, such as modulus of elasticity in bending, strength as a tool handle, etc., should be referred to.

There are other terms like *stiffness, toughness, brashness, resilience, brittleness*, which have specific significance to one or more mechanical properties of the material combined with its size, shape and condition. It is not proposed to discuss here the detailed aspects concerning these terms, but it is recommended that for a comprehensive understanding of mechanics of timber reference be made to more advanced text books on the subject. However, these terms also are described briefly later wherever they find mention.

At this stage, it would also be necessary to have an elementary understanding of the orthotropic nature of wood, because of which its mechnical properties are different in the three mutually-perpendicular axes of structural symmetry. These axes correspond to the radial, tangential and longitudinal directions of the wood structure. Their significance is due fundamentally to the relative position of fibres, ray-cells, growth rings and other elements of wood. A surface governed by longitudinal and radial direction is known as the *Radial plane* and, similarly, the surface governed by logitudinal and tangential alirection is known as the *Tangential plane*. The surface governed by both radial and tangential directions is known as the *Cross-section plane* or *Transverse plane*. In order to understand the comprehensive mechanical behaviour of wood, keeping in view its orthotropic nature, all forces acting in different directions and

TABLE X—2

Coefficients of variation for different properties of timber

	Property	Average	Minimum	Maximum
Specific gravity (based on weight oven dry and)	Volume at Test	5.2	0.6	12.7
	Volume Oven dry	6.0	1.5	11.9
Shrinkage % Green to oven dry	Radial	12.0	2.6	26.3
	Tangential	9.2	3.7	22.5
	Volumetric	8.0	2.6	21.2
Static bending	Fibre Stress at Elastic Limit	10.4	3.6	27.5
	Modulus of Rupture	7.8	3.0	22.7
	Modulus of Elasticity	10.5	2.7	31.8
Work—	To Elastic Limit	16.6	3.9	42.6
	To Maximum Load	16.0	5.8	29.4
	Total	18.7	4.5	71.7
Impact bending	Fibre Stress at Elastic Limit	8.7	3.3	23.2
	Max. Height of Drop of 50 lb (old) or 25 kg (new) hammer	12.0	2.9	32.0
	Modulus of Elasticity	12.3	3.3	38.4
	Work to Elastic Limit	9.4	2.4	18.6
	Brittleness (Izod test)	19.0	4.3	38.2
Compression parallel to grain	Comp. Stress at Elastic Limit	12.9	4.2	37.9
	Max. Crushing Stress	9.4	2.4	22.9
	Modulus of Elasticity	12.3	2.3	31.5
Compression perp. to grain	Comp. Stress at Elastic Limit	14.4	5.4	31.8
Hardness (Load in kg to embed 1.128 cm diameter ball to half dia.)	Radial	12.3	3.1	24.5
	Tangential	11.6	4.5	29.5
	End	10.7	3.4	23.7
Shear parallel to grain	Radial	10.6	3.3	21.1
	Tangential	10.4	1.8	20.2
Tension perp. to grain	Radial	17.0	2.9	44.4
	Tangential	15.8	5.5	35.1
	Average Y. Point (Intersection point)	4.0	1.1	9.0
	Average	11.5	3.2	28.7

different surfaces (or planes) require to be resolved in the directions of three principal axes, and sorted out in order to determine which of them act on which of the three planes and what effects they have simultaneously on all these planes and in all the directions. The orthotropic nature of wood has been found to have many advantages in some industrial uses like plywood, laminated boards, etc.

Standard Tests on Timber Specimens

All strength data of timber are obtained mainly by testing *small clear specimens*, also known as *standard specimens*, because (1) the most reliable comparison of different species is obtained only by testing pieces free from any types of defects and (2) the expenses involved in collection of material, preparation of specimens and testing should be as low as possible without prejudice, however, to the securing of an acceptable average for the strength properties of the species as a whole. The data thus obtained should be capable of being used with adequate safety factors for design purposes, and also for establishing the suitability of various timbers for many industrial and domestic applications. With these in view, standard specimens of 5 cm × 5 cm cross-section are now used in India, the length and shape of the specimens being, however, different for different mechanical and physical properties; this conforms to the practice obtaining in most English-speaking countries. In many countries of Europe, the standard size is 2 cm × 2 cm. Both the sizes are at present internationally recognized standards, and in some countries both are used simultaneously with a view to comparing the results of one with the other.

It may be stated that while the methods of carrying out the tests are in general well standardised in many parts of the world, all the tests are not necessarily carried out as a standard routine by the various testing authorities. In India, 11 mechanical tests and 6 physical tests are carried out as a routine on all species of timber using samples from different localities. Table No. X-3 indicates the mechanical tests in the order of their importance together with details on standards regarding sizes of the testing specimen, scheme of selection of those specimens from a log, loading conditions, testing methods and properties determined, etc. Among the rutine physical standard tests is included in determination of moisture content, specific gravity, radial, tangential and volumetric shrinkage, and a few structural characteristics, such as percentage of sapwood present, width of the annual rings, interlocking in grain, etc.

The various species of timber are collected from as many localities as possible within the geographical range of the species in accordance with the set of instructions given in Appendix II. From each locality, 10 logs of sound straight-grained trees of merchantable size and of average age are selected. Necessary information on the local conditions, such as soil, elevation, surroundings, usual climate, etc., is also collected in the field notes. When the logs are received in the laboratory, their condition is recorded; where necessary their photographs are also taken for record and marked as shown in Fig. X-3 to convert into scantlings or "stricks" for obtaining specimens for the various

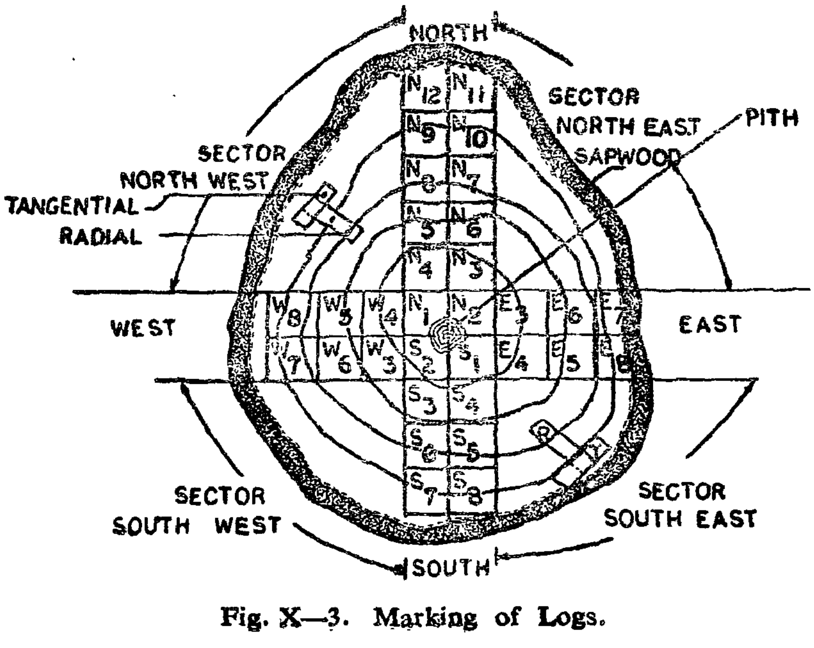

Fig. X—3. Marking of Logs.

[*Contd. on page* 122]

TABLE

Standards for mechanical tests on

Sl. No.	Mechanical test	Size of specimen	Scheme of selection of specimen, i.e., lay out	Speed of loading head
1	2	3	4	5
1.	Static Bending	5 cm × 5 cm × 75 cm on a span of 70 cm.	Specimens are selected from 50% of the sticks from the "composite bolt".	2.5 mm/min.
2.	Impact Bending	-do-	Six specimens from representative sticks of a "composite bolt".	Increment of 2.5 cm up to 25 cm and 5 cm beyond 25 cm, until complete failure or deflection of 15 cm is reached.
3.	Compression parallel to grain	5 cm × 5 cm × 20 cm on a guage length of 15 cm.	One piece from every stick.	0.6 mm/min.
4.	Compression perpendicular to grain	5 cm × 5 cm × 15 cm.	One piece from each of 50% sticks from which static bending pieces have been taken.	-do-
5.	Indentation test (Hardness)	-do-	One piece from each of other 50% sticks.	6 mm/min.
6.	Shear	5 cm × 5 cm × 6.25 cm with a corner notch to produce failure on 5 cm × 5 cm surface.	Six pairs from representative sticks of a log.	0.4 mm/min.

X—3

small clear specimens of wood

Surface on which load is applied	Properties determined	Remarks
6	7	8
Tangential surface nearer to the heart.	FS at LP, M of R, M of E, Work to EL, Work to Max. Load, Total Work, HS at LP, HS at ML.	Deflections are measured correct to 0.2 mm at load intervals of 50 kg to the proportional limit, and thereafter the machine is kept in balance upto or beyond the maximum load as the case may be. In the latter case, test should be continued to a deflection of 15 cm or until the specimen fails to support 100 kg, whichever occurs first.
-do-	FS at LP, M of E, Work to EL, Max. height of drop, Height-of-drop at LP.	Test done on a Hatt-Turner impact bending machine with increment drops of 50 lb (old) or 25 kg (new) hammer. At present deflections are measured correct to 0.02 mm from recordings on a sheet wound round a drum. Drops are continued until a deflection of 15 cm or failure, whichever is earlier.
Cross section.	CS at LP, CS at ML, M of E in compression parallel to grain.	Deflections are measured correct to 0.002 mm. The load is applied through spherical seated block of self-aligning type.
Radial surface.	CS at LP, Compressive stress at compression of 2.5 mm, CS at ML, M of E in comp. perpendicular to grain.	Deformations are measured correct to 0.02 mm up to 2.5 mm and load is applied on central 5 cm portion. Load is applied through bearing plates 5 cm wide.
Two penetrations on radial and two on tangential surface and one on each end.	Max. load to embed a steel ball of 1.128 cm dia. to half its dia.	The penetrations should be far enough, from each other and from the edges, to prevent splitting or chipping.
One for radial and one for tangential.	$MSS = \frac{\text{Maximum Load}}{\text{Shearing area}}$	If a special shearing tool with self-adjusting bearing surface and special arrangement for holding the specimen is employed, such that the specimen is supported on end-grain surfaces and the end rests evenly on the support throughout the contact area, then the failure will be as a result of the shear in the required plane.

(Contd.)

TABLE

1	2	3	4	5
7.	Tension perpendicular to grain	50 cm × 50 cm × 56 cm with semicircular notches for gripping so as to produce a failure on a 50 mm × 20 mm area in the radial or tangential plane.	Six pairs from representative sticks of a "composite bolt".	2.5 mm/min.
8.	Tension parallel to grain	7 mm × 7 mm cross section, 5 cm gauge length shoulders and wide surface for gripping.	Pieces from representative portions of "composite volt".	1.0 mm/min.
9.	Torsion	Cylindrical specimen of 25 mm diameter, gauge length 15 cm and grips of 30 cm × 30 cm × 40 cm at each end.	6 specimens from an end bolt of 0.3 m length in the same log.	Torque is applied at the uniform rate of 600 cm-kg/min.
10.	Nail and screw pulling test	5 cm × 5 cm × 15 cm.	From available material of the "composite bolt" or sectors of the logs.	2.0 mm/min.
11.	Brittleness test	(a) Izod test 22 mm × 22 mm × 125-150 mm. (b) Charpy test 1.25 mm × 125 mm with notches in each case.	One specimen from each of static bending and impact bending tested specimens. To be done not as a routine but only on optional basis.	The impact blow should be given by releasing the pendulum and allowing the same to fall freely.

X-3 (*Concld.*)

6	7	8
One for radial and one for tangential.	$\frac{\text{Maximum load}}{\text{Tension area}}$	The grips for holding the specimen should be properly designed so that there may not be any slip, and pulling across the fibres is, as far as possible, perpendicular to the grain.
Cross-section.	TS at LP, TS at ML, and M of E in tension.	The grips for holding the specimen should be so designed as to avoid any slipping, and such that pulling along the fibres is, as far as possible, parallel to the grain and there should not be any shear failure at the grips. Elongation should be measured correct to 0. 002 mm by an extensometer at regular load intervals of 50 kg.
Cross-sectional rotation.	Torsional shear stress at limit of proportionality (TSS at LP), Torsional shear stress at maximum torque (TSS at MT) and Torsional modulus of rigidity.	The angular twist should be measured in degrees at regular intervals of 25 cm kg torque correct to 0.5 min.
Two nails on radial surface, two screws on tangential surface and one each on end surfaces.	Maximum withdrawl load under three conditions: (a) Nails and screws driven in green condition and pulled out at once. (b) Driven in green and pulled in dry condition and (c) Driven in dry and pulled in dry condition.	Nails shall be 5 cm long and bright galvanized and diamond-pointed. Screws should be 8 SWG galvanized gimlet-pointed. Each nail and screw should be used only once.
22 mm × 12 mm cross section at a distance 75 mm from one end on the tangential side for Izod test, and 10 mm × 12.5 mm at the centre on the revers side in case of Charpy test.	Energy absorbed in breaking the specimen on a single blow. Expressed in units of cm kg.	Any swinging pendulum machine should have a calibrated dial to give the direct recording of the energy absorbed in breaking the specimen in a single blow.

tests in 'green' and 'dry' (kiln or air-dry as the case may be) conditions. All the even-numbered sticks from the upper half of the log and the odd-numbered sticks from the lower half of the log are sorted out for testing in green condition; the rest will be tested in the air-dry or kiln-dry condition, as the case may be. All sticks to be tested under one required condition, bundled together, are called *composite bolts*. Of the 10 logs, there are thus 20 composite bolts; of these ten are usually tested in green condition, 8 in air-dry condition, and 2 in kiln-dry condition. The details of the procedures for conversion, distribution, testing and computation of data are currently described in the I.S., 1708 Part I (1960) & II (1963). "Methods of testing small clear specimens of timber".

The details of the Standards are given in Table X—3 and the sizes and shapes of standard test specimens are indicated in Fig. X—4 (a) & (b). The various formulae employed for computing the different properties from the data obtained in the tests are given below along with the description of some salient features of the tests, their importance, and the usefulness of properties mentioned. Wherever *proportional limit* is to be fixed for evaluating a property, it is found from load and deformation curves drawn either from the data collected on individual specimens or recorded automatically while testing. In some cases it may be difficult to locate the exact proportional limit, but the best curve is fitted by sight and the best judged point, where the linearity changes into non-

(a)

(b)

(c)

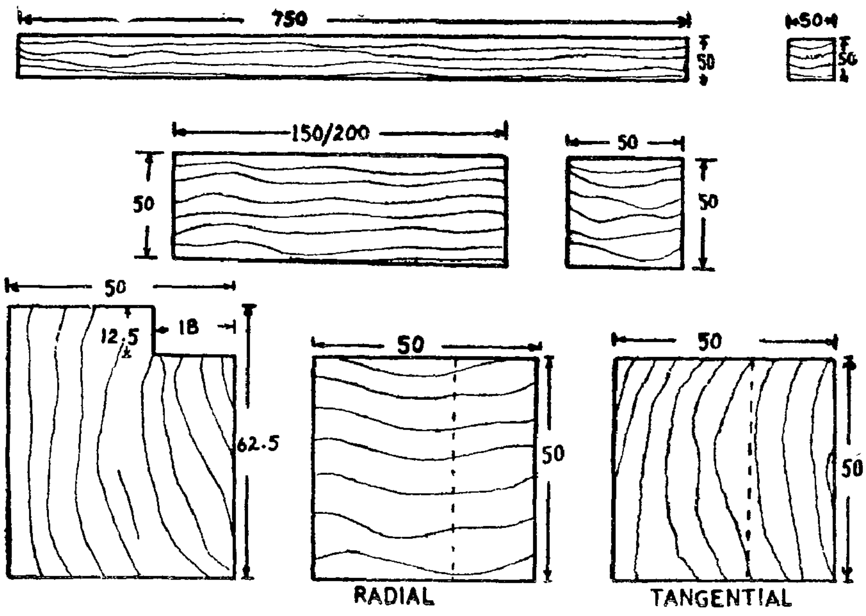

Fig. X—4 (a). Specimens for standard tests. (Dimensions in mm)

(a) Static Bending & Impact Bending

(b) Compression Parallel to Grain (200 mm)
Compression Perpendicular to Grain (50 mm)
Hardness (Indentation (150 mm)
Nail & Screw Holding (150 mm)

(c) Shear

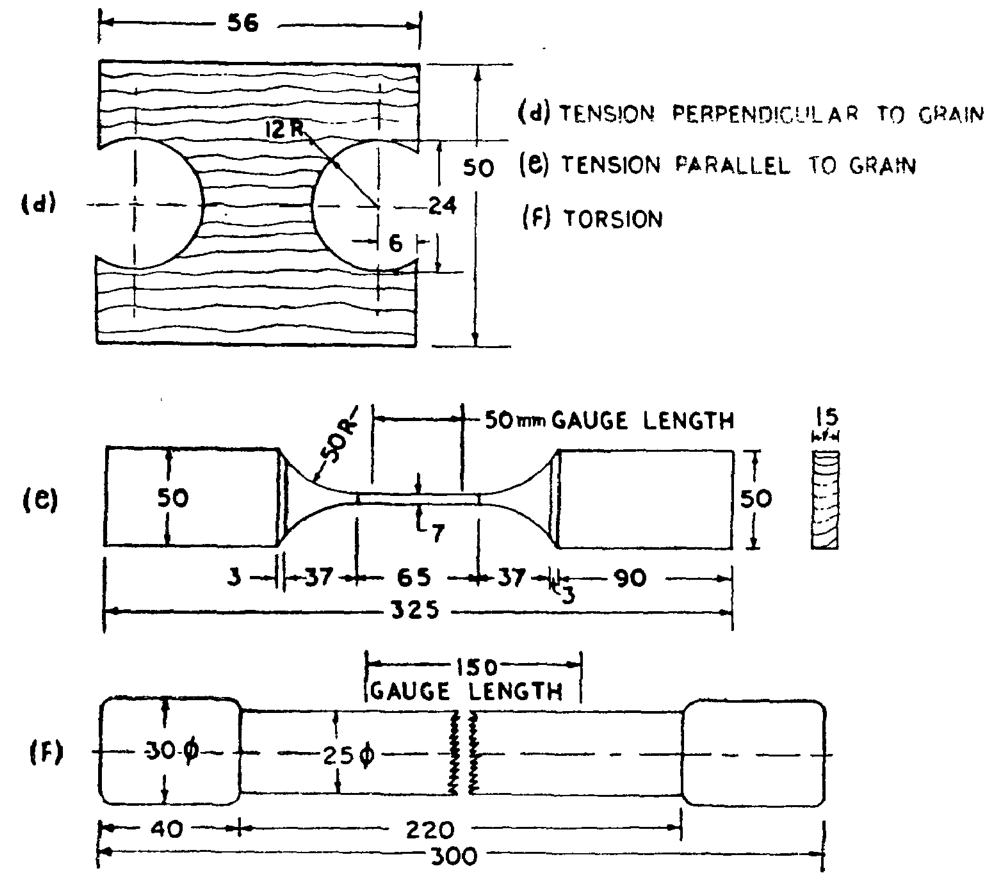

Fig. X—4 (b). Specimens for standard tests. (Dimensions in mm)

linearity, taken as the proportional limit. The usual data and typical load deformation curve drawn on a "log sheet" for a static bending specimen are given in Fig. X—5. Wherever areas are required to be measured on the graphs, they are measured directly or by calibrated planimeters.

Static bending test.—The test should be conducted on a suitable testing machine with the specimen mounted on a specially designed rig and the load applied centrally on a span of 70 cm. Where standard-size specimens are not obtained, the span will be 14 times the depth (also sometimes referred to "height") of the specimen. The load and the deflection of the neutral plane are measured at frequent intervals and also at various stages of failures or sudden changes in deflections or loads. The readings are also noted at the maximum load and at final failure. The type of final failure that occurs on the test specimen is also to be recorded and classified according to its appearance and development as indicated in Fig. X—6. From the load-deflection data, a smooth curve is drawn to find the proportional limit. The following strength properties are computed, using the formula given against each.

Sl. No.	*Mechanical property*	*Unit*	*Formula*
1.	Fibre stress at limit of proportionality : FS at PL (or FS at EL)	Kg/cm²	$\frac{3\,Pl}{2\,bh^2}$
2.	Equivalent fibre stress at maximum load (Modulus of rupture): M of R	Kg/cm²	$\frac{3\,P'l}{2\,bh^2}$
3.	Modulus of elasticity: M of E	1000 kg/cm² or metric tonnes/ cm²	$\frac{Pl^3}{4\Delta bh^3} \times \frac{1}{1000}$
4.	Horizontal shear stress on neutral plane at limit of proportionality: HSLP	kg/cm²	$\frac{3P}{4bh}$
5.	Horizontal sheai stress on neutral plane at maximum load: HS at ML	kg/cm²	$\frac{3P'}{4bh}$
6.	Work to limit of proportionality (elastic resilience) : Wk to LP (or Wk to EL)	Kg cm/cm³	$\frac{CA}{lbh}$
7.	Work to maximum load: Wk to ML	kg cm/cm³	$\frac{CA'}{lbh}$
8.	Total work	kg cm/cm³	$\frac{CA''}{lbh}$

Where,

b= breadth of the test specimen in cm;

h= depth of the test specimen in cm, sometimes known as "height" of the specimen;

l= span of the test specimen in cm;

P= load in kg at the limit of proportionality obtained from load-deflection curve;

P′= maximum load in kg;

Δ= deflection in cm at the limit of proportionality obtained from load deflection curve

A= area in sq cm bounded by load-deflection curve to limit of proportionality, the x-axis and the ordinate at the limit of proportionality;

A′= similar area in cm^2 up to maximum load

A″= similar area in cm^2 up to the final reading, i.e., break point; and

C= area constant in kg cm (i.e; the energy, represented by one square centimetre which is equal to load in kg, represetned by one centimetre on the ordinate, multiplied by deflection in centimetres, represented by one centimetre on the abscissa).

The properties evaluated under this test are useful in all engineering constructions and also in deciding suitability of species for beams, deckings, axles, wood poles, etc.

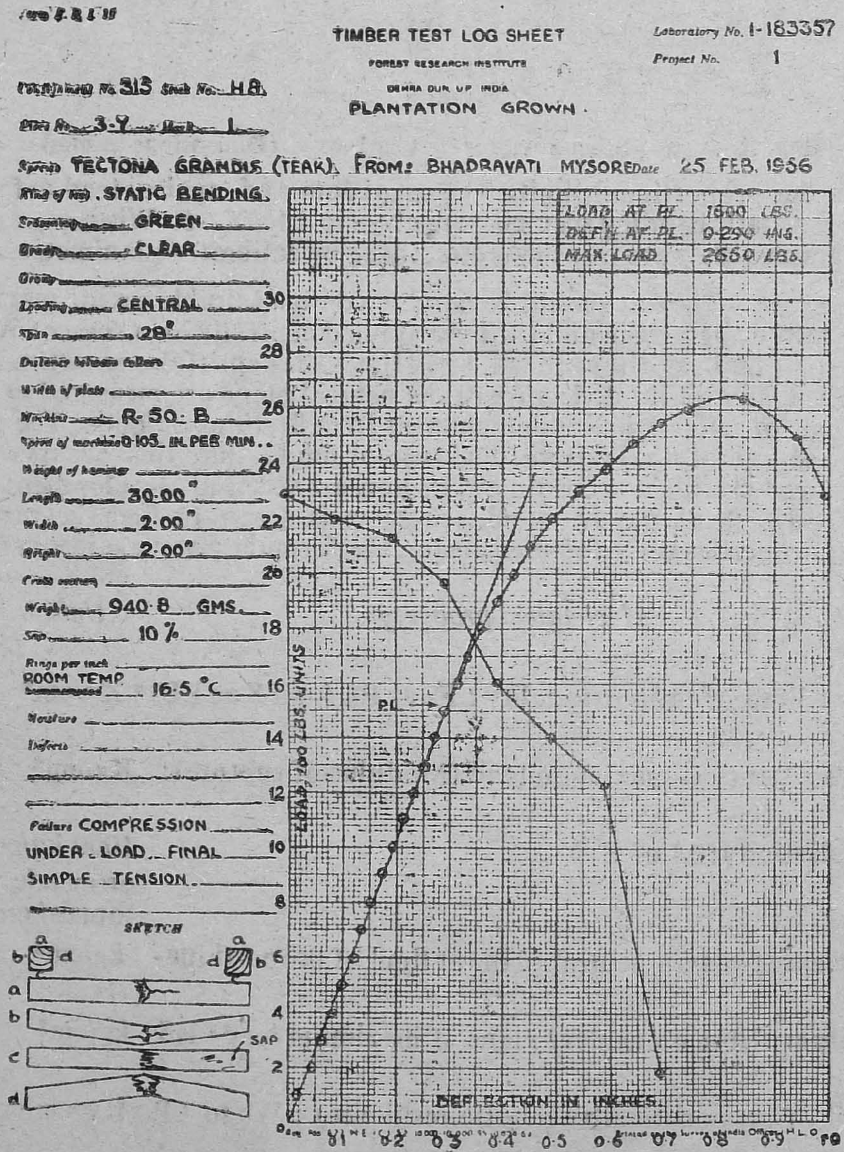

Fig. X—5.

Impact bending test.— These tests are usually done on a "Hatt Turner" machine, from which the deflection due to successive drops of a freely falling hammer on the specimen are directly recorded with reference to a datum line on a sheet of paper stuck on a drum. If 'x' is the static deflection due to the

weight of the hammer, measured correct to 0.02 mm, and 'y' is the deflection noted on the recording sheet with reference to the datum line, then (y+x) is taken as the deflection due to the impact load obtained for the specific fall of the hammer from a total height 'H'. A graph is plotted between 'H' and $(y+x)^2$ and from it the limit of proportionality is found. The various properties are computed from the

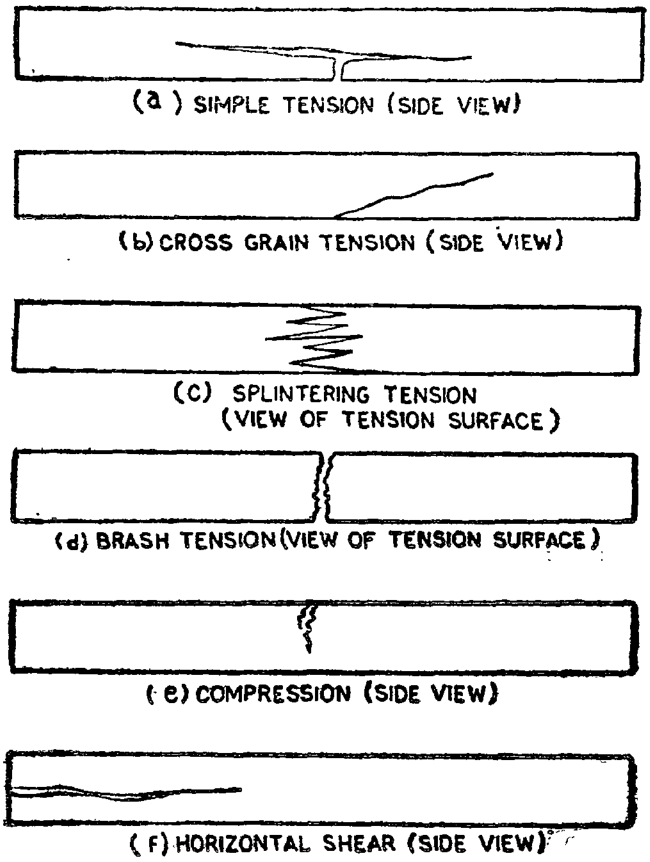

Fig. X—6. Types of failures in bending.

following formulae. The failures under impact loads are recorded and classified according to their appearance and development as indicated in Fig. X—6.

Sl. No.	*Mechanical property*	*Unit*	*Formula*
1.	Maximum height of drop	cm	H
2.	Height of drop at limit of proportionality	cm	H'
3.	Fibre stress at limit of proportionality : FS at LP	kg/cm^2	$\frac{3\ WH'l}{bh^2\Delta}$
4.	Modulus of Elasticity: M of E	1000 kg/cm^2 or $tonnes/cm^2$	$\frac{WH'l^3}{2\ bh^3\Delta^2} \times \frac{1}{1000}$
5.	Work to limit of proportionality: Wk to LP or (Wk to EL)	$kg\ cm/cm^3$	$\frac{WH'}{lbh}$

Where,

l = the span of the test specimen in cm ;

b = breadth of the test specimen in cm ;

H' = total height of drop in cm at the limit of proportionality from the curve;

h = depth of the test specimen in cm, sometimes known as "height".

W = Weight of the hammer in kg; and

Δ = (y+x) at limit of proportionality from the curve.

The properties evaluated under this test will be useful to decide the suitability of timbers for various purposes where shocks come into play, such as tool handles, railway sleepers, agricultural implements, etc.

Compression parallel to grain.—This test can be done on any testing machine, care being taken that the application of load is in the same direction as the grain of the specimen parallel to its lengthwise edges. A slope of grain not more than 1 in 20 with the longitudinal edge of the specimen is permissible. When the standard size of the specimen is not available, the length of the specimen is generally taken to be not more than four times the shorter dimension of the cross-section. The deformation under compression is plotted directly with the help of a compressometer, lamp and telescope, or plotted separately if measured otherwise. The test is carried on until maximum load is reached and final failure is observed. The failures are classified according to their appearance and development as indicated in Fig. X—7.

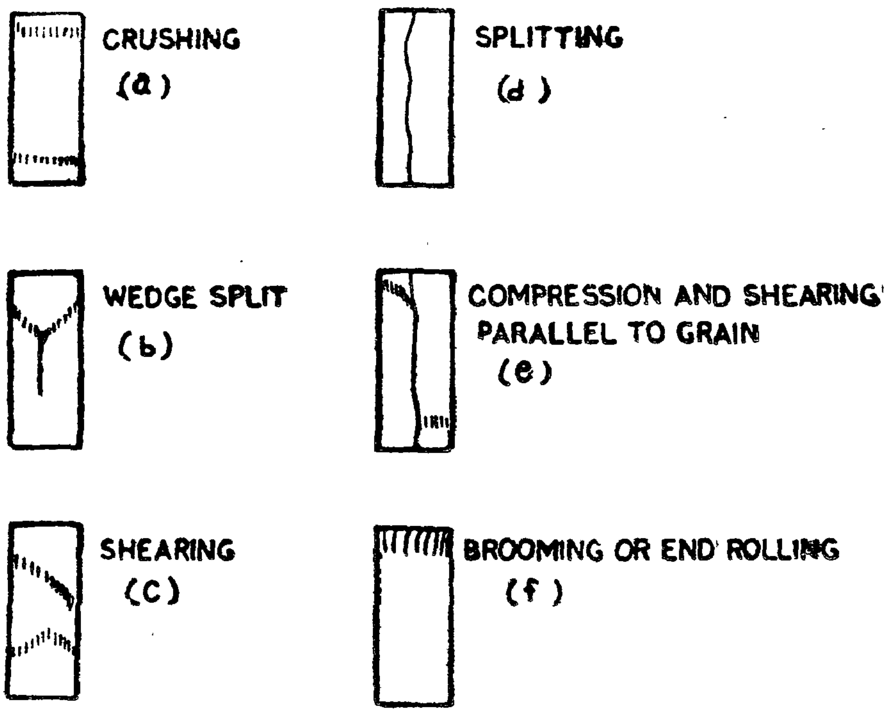

Fig. X—7. Types of failures in compression parallel to grain.

From the load-compression curves, the proportional limit is evaluated; the strength properties are computed using the following formulae.

Sl. No.	*Mechanical property*	*Unit*	*Formula*
1.	Compressive stress at limit of proportionality : CS at LP	kg/cm^2	$\frac{P}{A}$
2.	Compressive stress at maximum load : CS at ML	kg/cm^2	$\frac{P'}{A}$
3.	Modulus of elasticity in compression parallel to grain : M of E	1000 kg/cm^2	$\frac{lP}{\Delta A} \times \frac{1}{1000}$

Where,

A = cross-sectional area of the test specimen in sq cm;

l = gauge length between the end points of compressometer points in cm;

P = load at the limit of proportionality in kg;

P′ = maximum crushing load in kg; and

Δ = deformation (i.e., compression) at the limit of proportionality in cm.

These properties are useful in the design of columns, evaluating suitability of species for posts, and many other industrial purposes where forces act in a direction parallel to the grain of timber, such as bearing blocks, textile goods etc.

Compression perpendicular to grain.—Unlike in the previous test, the load is applied in a direction perpendicular to the grain on the radial surface. It is not always possible to test the specimen to the maximum load and, as such, a maximum compression limit of 2.5 mm is generally fixed so that the elastic limit in most of the species would be reached at this limit. From the load-compression curves the following properties are evaluated at the limit of proportionality and at other points :

Sl. No.	*Mechanical property*	*Unit*	*Formula*
1.	Compressive stress at limit of proportionality : CS at LP	kg/cm²	$\frac{P}{A}$
2.	Compressive stress at compression of 2.5 mm	kg/cm²	$\frac{P'}{A}$
3.	Crushing strength at maximum load : CS at ML	kg/cm²	$\frac{P''}{A}$
4.	Modulus of elasticity in compression perpendicular to grain : M of E	1000 kg/cm²	$\frac{Ph}{\Delta A} \times \frac{1}{1000}$

Where,

A = area in sq cm of the section of the specimen at which load is applied normal to the direction of grain;

P = load at limit of proportionality in kg;

P′ = load at 2.5 mm compression in kg;

P″ = maximum load if reached at a compression less than 2.5 mm;

Δ = deformation at the limit of proportionality in cm; and

h = depth of the specimen in cm (sometimes known as "height").

The data obtained form the test would be useful for choosing species suitable for special purposes in which the loads are applied on the lateral surfaces of the members, as in bearing surface, bolted timber, furniture, instruments, railway sleepers, some types of sports goods, etc.

Indentation test.—This test is intended primarily to find out the surface hardness of the various species, and is evaluated in terms of the load required to embed a standard-size steel ball to half its diameter. The details of test are given in Table No. X—3 (page 118); it can be done on any universal testing machine with appropriate tools. This property is also often taken as an indication of the capacity for resistance to *abrasion* in the absence of a separate test for the same. Although hardness is found separately on radial, tangential and end surfaces, the average of the radial and tangential values is often given as side hardness. It may be interesting to note that in many Indian timbers the hardness figure for the end surface, i.e., on cross-sectional area, is more than that for side surfaces. This property is useful in deciding the suitability of timber for uses in which there is a continuous abrasion on the surface of the timber, such as paving blocks, ship deckings, floorings, furniture, railway sleepers, tool handles, etc.

Shear parallel to grain.—This test is primarily intended to evaluate the behaviours of timber under shearing forces which may result in one portion of the material sliding over the adjoining portion along the fibres. The surface of failure in the standard tests may be either radial or tangential. Often, the average of the values in the two planes is given as shear parallel to grain. This value is useful in the design of various articles used in the industry, such as agricultural implements, lorry-body building, bearing and packing blocks, etc. This value multiplied by 1.07 and with an appropriate factor of safety, is also taken for consideration of permissible horizontal shear in the design of beams. The *maximum shearing stress,* also known loosely as shering *strength,* is evaluated by dividing the total load required for failure by the area separated out.

Tension perpendicular to grain.—This test is primarily intended to evaluate the mechanical forces required for splitting timber into parts. The cleavage may be either on the radial plane or on the tangential plane. While in India a piece is pulled apart across the fibres held in double hooks or clamps

fitted into notches at both the ends, in some other countries a separate cleavage test is also performed in which the grips are fitted into a notch at one end of the specimen only. The maximum tensile stress across the grain is obtained by dividing the maximum load by the area that failed under tension. The average values obtained for radial and tangential planes are used for evaluating the splitting coefficients for various species. This property is also employed for determining the suitablility of species for such industrial purposes as textile goods, patterns for casting, furniture, carvings, etc. This property is also considered for those uses in which the weathering conditions adversely affect the timber.

Tension parallel to grain.—This test is primarily intended to determine the ability of timber to withstand forces, when pulled apart in the longitudinal direction of the fibres. To achieve the best results in tests, special self-aligning and self-tightening grips are required. The gripping characteristics should be such that no shear or compression failure occurs at the ends where specimens are held before any failure occurs under the pure tensile stress at the smallest cross-section in the test specimen. The elongation is measured correct to 0.002 mm, either by a calibrated extensometer or by a mirror and scale, at regular load intervals. A graph is plotted showing elongation against load, and a sketch is made of the type of the failure. The strength factors in tension parallel to grain are computed by the formulae given below. Although the properties evaluated under this test are not directly employed anywhere, the data obtained are of indirect use in evaluating the suitability of timbers for purposes in which tensile stresses come into play as a result of the orthotropic nature of wood, and for comparison with other materials with regard to general mechanical behaviour.

Sl. No.	*Mechanical property*	*Unit*	*Formula*
1.	Tensile stress at limit of proportionality : TS at LP	kg/cm^2	$\frac{P}{A}$
2.	Tensile stress at maximum load : TS at ML	kg/cm^2	$\frac{P'}{A}$
3.	Modulus of elasticity in tension parallel to grain : M of E	$1000\ kg/cm^2$	$\frac{lP}{\Delta A} \times \frac{1}{1000}$

Where,

A = cross-sectional area, in cm^2;

l = gauge length between extensometer points, in cm;

P = load at the limit of proportionality, in kg;

P′ = maximum load to cause the failure of the specimen in kg; and

Δ = elongation measured in cm at the limit of proportionality.

Torsion test.—Torsion tests are made on cylindrical straight-grained specimens, care being taken to see that there is no relative slip at the gripping ends. The angular twist is measured on a central gauge length, and a graph is plotted showing torque against the angular twist so as to locate the proportional limit. The various torsional properties are computed from the formulae given below. The properties determined under this test are useful in evaluating the warping characteristics of the species and examining the suitability of species for such purposes as agricultural implements, aircraft construction, axles, etc.

Sl. No.	*Mechanical property*	*Unit*	*Formula*
1.	Torsional shear stress at limit of proportionality : TSS at LP	kg/cm^2	$\frac{2M}{\pi r^3}$
2.	Torsional shear stress at maximum torque : TSS at MT	kg/cm^2	$\frac{2M'}{\pi r^3}$
3.	Torsional modulus of rigidity	$100\ kg/cm^2$	$\frac{2Ml}{\pi r^4 \theta} \times \frac{1}{100}$

Where,

M = resisting moment in cm-kg at the limit of proportionality, i.e., the moment of the couple as measured directly on the machine;

M^1 = resisting moment at maximum torque in cm-kg;

r = radius of the portion of the specimen under test in cm;

l = length of the specimen over with torsion is measured in cm (i.e., gauge length); and

θ = the angular twist of one end relative to the other end at a distance of 'l' and expressed in radians at proportional limit.

Brittleness tests.—(Izod and Charpy tests)--Compared to the method of impact bending mentioned earlier, these tests are performed on smaller samples, and more quickly, for evaluating the shock-resisting ability of timbers and also for studying the stress-concentration effects on the toughness characteristics of the timber due to various types of notches, etc. Both the tests are of single-blow type under a swinging pendulum and are, therefore, somewhat different from the multiple-blow type under the Hatt-Turner machine. The only property evaluated is the energy absorbed in breaking the standard-size specimens as read directly from a calibrated dial, and this provides data for comparison and not for any basic design purposes. Several studies have been made on the variation of the energy absorbed for different shapes of notches and specimens, on the basis of which standard-sizes of the specimen have been arrived at (Sekhar & Negi : 1955/57).

Nail and screw-pulling tests.—These tests, under standard conditions, provide necessary information with regard to the use of timbers in construction, packing cases, and various types of joinery in which nails and screws are used. The data will be helpful not only in assessing withdrawal resistance of nails and screws under different conditions of use of the material, but also in evaluating the comparative suitability of the species by computing the composite holding power. (Sekhar and Rana : 1956). As in the case of hardness, the average withdrawal resistance on the radial and tangential surfaces is sometimes given as side-withdrawal resistance or side-holding power. While it has generally been observed that the side-holding power is more than that of the end-holding power, there are also a few instances in which the end-holding power of nails is more than the side holding power.

Specific gravity.—Immediately after each test described above, from static bending test to nail and screw-pulling tests, whether in dry or in green condition, a *moisture disc*, approximately 2.5 cm in length and comprising a full section of the test piece, is taken normally at the place of failure or at the central portion of the tested specimen. The moisture content of this section is determined by first weighing the specimen immediately after cutting (W_1) and then drying it in an oven at a temperature of $103° \pm 2°$ C, until its weight is constant (W_0). The loss in weight expressed as a percentage of the final oven-dry weight, i.e., $\frac{100(W_1-W_0)}{W_0}$, is taken as the moisture content of the whole test specimen. The weight of the whole specimen determined at the beginning of the test, divided by its volume obtained directly by measurement of its dimensions, is then taken as the specific gravity of the specimen at test and converted to standard specific gravity by the formula :

$$\text{Std. Sp. Gr. } (\rho) = \text{Sp. Gr. at test } (\rho_m) \times \left(\frac{100}{100+m}\right)$$

$$\text{i.e., } \rho_m \left(\frac{100}{100+m}\right)$$

Other routine physical tests.—In addition to the mechanical tests described above, some physical tests are also carried out as a routine in most of the timber-testing laboratories. These are described briefly in the paragraphs given below.

(1) *Specific gravity and volumetric shrinkage.*—The specific gravity and volumetric shrinkage tests are done on the same pieces of clear specimens, 5 cm × 5 cm × 15 cm, with the necessary precautions taken to prevent end cracking. The specimens are weighted correct to 0.1 gram, and volumes are determined by immersion method (Archimedes' Principle). The properties are calculated by the following formulae :

(i) Specific Gravity at test ρ_m (i.e., at a given moisture content 'm')

$$\frac{\text{Wt. of the specimen at the given moisture content}}{\text{Volume of the specimen at the same moisture content}}$$

(ii) Standard Specific Gravity

$$= \frac{\text{Weight in oven dry condition } (W_o)}{\text{Volume in the green condition } (V_g)} = \rho_m \left(\frac{100}{100+m}\right);$$

(iii) Weight in kg/cu m at a given moisture content 'm'— $\rho_m \times 1000$;

(iv) Volumetric shrinkage (%) from green to moisture content 'm'

$$= \left(\frac{V_g - V_m}{V_g}\right) 100; \text{ and}$$

(v) Moisture content 'm' (%) $= \left(\frac{W_m - W}{W_o}\right) 100.$

Where,

V_g = volume in the green condition;

V_m = volume at required moisture content which may be 12% or 0% (usually, in the reports of standard data, only the case 'm' = 0 is considered);

W_m = weight of the specimen at a given moisture content 'm'; and

W_o = weight in the oven-dry condition.

(2) *Radial and tangential shrinkage.*—These tests are made on specimens of the size 2.5 cm × 2.5 cm × 10 cm, cut truly radially or tangentially in the lengthwise direction. The specimens are weighed correct to 0.01 gm, and lengths of the pieces are measured correct to 0.02 mm. After noting the initial weights and lengths of the specimens, they are allowed to dry in air and are then weighed and measured periodically to the accuracy given above, until they reach about 12% moisture content. They are then dried in oven for complete removal of moisture. The shrinkage is calculated by the following formula :

$$\text{Shrinkage (\%)} = \left(\frac{L_i - L_m}{L_i}\right) 100.$$

Where,

L_i = initial length i. e., length, in green condition; and

L_m = length at the required moisture content, usually 12% or 0%.

A graph showing moisture content against shrinkage (radial or tangential) may be plotted from which the moisture content at which shrinkage commences appreciably is noted. This is sometimes known as *fibre saturation point* or 'Y_o' point. The significance of this point is that physical and mechanical properties do not change appreciably at moisture content above this value, but change considerably at moisture content below this point. The averge values of radial and tangential shrinkages are generally employed for computations for comparative studies. Similarly the average of radial and tangential shrinkage at 12% moisture content is also evaluated.

It may be noted that shrinkage-radial, tangential or volumetric-to the required moisture content (0% or 12%) is expressed as a percentage of the dimensions in the green condition, whereas the moisture content in timber is expressed as a percentage of the weight of the material in the oven-dry condition. This is so done because the volume in green condition does not appreciably change with moisture content and weight in oven-dry condition is not affected by the presence of moisture. It is for this reason that the standard specific gravity is expressed in terms of weight in the oven-dry condition and volume in the green condition.

(3) *Ring counting and percentage of sap.*—The growth rings, per 3-cm length, are counted in the radial direction on each of the cross-sections of the test piece by means of suitable micrometers fitted with eye-pieces. The average ring width or the number of rings per centimetre serves to indicate the rate of growth of the tree from which the material is taken. Variations in strength properties due to average or abnormal growth are studied in special cases. The sapwood, wherever it occurs in specimens, is expressed as a percentage volume for all such test specimens, and the differences in mechanical properties in the specimens from the periphery and from heartwood region are noted wherever necessary.

Tests required for different uses.—The principal and auxiliary tests required for different forms of use of timber are indicated in Table X—4 (page 131).

(Contd. on page 134)

TABLE X—4

Principal and auxiliary tests required for different uses of timber

Sl. No.	Uses	Comp. parallel to grain	Comp. perp. to grain	Static Bending	Impact Bending	Indentation	Shear	Cleavage	Tension parallel to grain	Tension perp. to grain	Shrinkage
1.	Athletic and sporting goods	x		0	x	x	0		0	0	0
2.	Axles	0	0	x	x	0	0				
3.	Beams		0	x	0		x	0	0		
4.	Bearing blocks		x			x		0			x
5.	Boat building :										
	Frames	0		x	x	0		0			
	Planking		0	x	x	x	0	0			0
	Decks			x	x	0	0	0			x
	Masts and spars		0	x	x			0			
6.	Bowls					x		0			x
7.	Bolted timbers	x	x				x	x		x	0
8.	Boxes		x	0	x	0		x			0
9.	Carving					x		0			0
10.	Columns, posts and struts	x		x		0	0	0			
11.	Cooperage			x	x		0	x			x
12.	Crates			x	0	0		x			
13.	Stock timber finished to size										x
14.	Flooring		x	x		x		x			x
15.	Furniture	x		x	0	0	0	x		0	x
16.	Joints		x			0	0	x		x	x
17.	Joists		x	x	0		0		0		
18.	Mallets					x	0	0			
19.	Nailed timbers					x		x		0	
20.	Notched timbers		x		0	0	x	x		x	
21.	Panelling							0			x
22.	Patterns					x					x
23.	Paving blocks	x		0		x	0	0			x
24.	Pencils					x		0			
25.	Rollers		x	0		x	x				0
26.	Shears					x	x	0			0
27.	Shuttles		0			x		x		0	x
28.	Sleepers	x	x	x		0					
29.	Spokes			0	x						0
30.	Tool handles	x	x	0	x	0		x			0
31.	Wedges	x	x			x					x
32.	Wheel wright's work	0	x	x				x		x	x

x=Principal tests.

0=Auxiliary tests.

TABLE

Suitability coefficients for some

Sl. No.	Species	Locality from where tested	Weight in terms of Teak	Strength as a beam
1	2	3	4	5
1.	*Tectona grandis* (teak) Standard	Malabar, Nilambur and Coimbatore	100	100
1.	*Abies pindrow* (fir)	Simla, H. P.	75	70
2.	*Acacia nilotica* (*A. arabica*) (babul)	Saharanpur, U. P.	115	90
3.	*Adina cordifolia* (haldu)	Haldwani, U. P.	95	75
4.	*Albizia procera* (safed siris)	Dehra Dun, U. P.	95	85
5.	*Azadirachta indica* (neem)	Kanpur, U. P.	120	85
6.	*Boswellia serrata* (salai)	Hazaribagh, Bihar	80	55
7.	*Canarium strictum* (safed dhup)	N. Mangalore, Madras	95	85
8.	*Cedrela toona* (toon)	Dehra Dun, U. P.	70	55
9.	*Cedrus deodara* (deodar)	Simla, H. P.	80	80
10.	*Dalbergia sissoo* (sissoo)	U. P.	115	90
11.	*Diospyros melanoxylon* (ebony)	Nagpur, Maharashtra	120	75
12.	*Dipterocarpus macrocarpus* (hollong)	Lakhimpur, Assam	105	100
13.	*Grewia tiliaefolia* (dhaman)	Malabar, Madras	115	110
14.	*Hopea wightiana* (hopea)	Palghat, Madras	160	125
15.	*Juglans fallax* (walnut)	Kashmir	85	85
16.	*Lagerstroemia lanceolata* (benteak)	Nilambur, Madras	90	80
17.	*Mangifera indica* (mango)	Puri, Orissa	95	75
18.	*Mesua ferrea* (mesua)	Sibsagar, Assam	140	145
19.	*Michelia* spp. (champ)	Bengal	70	65
20.	*Morus laevigata* (bola)	Andamans	85	80
21.	*Picea smithiana* (spruce)	Simla, H. P.	65	60
22.	*Pinus roxburghii* (chir)	Ranikhet, U. P.	75	65
23.	*Pterocarpus dalbergioides* (padauk)	N. Andamans	105	100
24.	*Pterygota alata* (narikel)	Hathigaon, Assam	85	85
25.	*Quercus lamellosa* (oak)	Darjeeling, Bengal	125	105
26.	*Shorea robusta* (sal)	Balaghat, M. P.	120	105
27.	*Tectona grandis* (teak)	Malabar, Madras	100	90
28.	*Terminalia tomentosa* (laurel)	Malabar, Madras	130	85
29.	*Tsuga dumosa* (*T. brunoniana*) (hemlock)	Darjeeling, Bengal	60	50
30.	*Xylia xylocarpa* (irul)	N. Kanara, Maharashtra	125	100

X—5

important species and purposes

Stiffness as a Beam	Suitability as a Post or Strut	Shock resisting ability	Retention of shape	Shear	Hardness	Splitting Coefficient	Nail holding power	Screw power holding
6	7	8	9	10	11	12	13	14
100	100	100	100	100	100	100	100	100
85	80	75	65	80	65	80	100	75
80	80	135	80	175	145	120	145	110
75	80	80	80	110	110	105	125	95
80	85	140	75	130	105	115	125	95
80	80	115	70	150	140	125	150	115
60	55	65	90	85	60	90	110	80
100	85	95	65	100	85	95	115	90
65	60	60	65	100	65	75	95	70
80	85	60	85	90	70	55	100	75
80	85	140	85	145	145	125	150	115
75	75	115	60	110	115	125	150	110
120	105	105	50	105	95	110	130	100
120	120	145	60	140	155	130	140	110
130	130	155	60	180	225	160	190	145
90	80	105	65	105	75	90	105	80
95	85	110	65	95	90	90	110	85
80	75	100	95	105	90	115	130	95
150	150	160	55	145	215	105	175	135
75	70	75	75	80	60	75	95	70
75	75	155	70	110	95	95	110	85
75	75	55	70	70	55	75	90	70
80	70	80	70	70	50	80	100	75
105	105	100	100	115	130	75	135	105
85	85	100	70	90	75	105	125	95
120	95	130	45	145	140	125	155	115
110	105	115	60	110	120	125	150	115
95	95	85	85	110	105	110	135	100
90	85	105	60	125	165	135	165	125
60	55	55	70	70	40	70	85	65
105	105	90	65	155	195	130	155	120

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Suitability Co-efficients and Indices

Unlike other biological materials, wood has a wide range of application in many industrial and engineering fields but, as with most other biological materials, its variations in structure and non-homogeneity do not permit application of simple laws of mechanics on wood without making suitable approximation at different stages. In structures, wooden members are subjected to lateral loads as well as longitudinal loads. Wood has been employed in several places, such as flooring and decking, where surface-wearing qualities are more important than others. In some forms of use, as in tool handles and sports goods, its shock-resisting ability becomes more important. Owing to the operation of factors of importance of different kinds and degrees in different uses, only some woods become acceptable for certain uses. Sometimes, even among the limited number of species suitable for a particular use, comparative costs and availability will further restrict the final choice. Hence it has been found useful to evaluate quantitatively, as coefficients or indices, the comparative suitability of woods for different uses to guide selection of one or more species in preference to others. While these indices may not serve as a basis on which a design of the size and shape of the material can be made, they do serve as a useful guide to decide the superiority of one wood over another.

A technique for evaluating the suitability indices was evolved at the Forest Research Institute and comparative suitability indices, with teak as standard, have been worked out for a large number of species with reference to (1) strength as a beam, (2) stiffness as a beam, (3) suitability as a posts, (4) shock-resisting ability, (5) retention of shape, (6) shear, and (7) hardness (Seaman & Limaye : 1933; Limaye : 1954). Similar indices for the nail and screw-holding power and splitting coefficients have also been worked out for a number of Indian woods (Sekhar and Rana : 1956 ; Sekhar & Bhatia: 1960). A composite suitability index to guide the use of Indian woods for sleepers has also been evolved (Sekhar : 1956). The method of evaluating suitability coefficients is discussed in Appendix III. The suitability coefficients for some important timbers, in respect of some selected properties are given in Table No. X—5 on pages 132—33.

There are certain limitations in the use of these suitability indices. To begin with these indices do not provide any indication of the basic behaviour of the material in any use, and as such they serve only as a quantitative guide to the estimation of the relative importance and suitability of different species for specific uses. It is therefore logical that, wherever it can be preferred, only the basic property should be considered rather than the suitability index. The next limitation is that these indices do not present any single condition of use such as 'Green' or 'Dry', but represent a composite condition. While in most cases the relative suitability of a species may roughly remain the same in a single condition, this will not be true in species of exceptional behaviour in different conditions. For example, taking into consideration the Dry and Green conditions, unless the strength-moisture relation is similar for all the species in the Green as well as Dry conditions, the ultimate comparative suitability indices may not be completely valid. A third limitation of these indices lies in the very selection of principal and auxiliary mechanical and physical properties, as it may not always be possible to associate all the properties that come into play for any use. Also, the weightage factors are often chosen rather arbitrarily. However, these conditions will indicate that while the actual values of a suitability index may vary, the relative superiority or inferiority of one species to another will still continue to hold good even with different arbitrarily selected properties and weightage factors. One of the very practical uses to which the suitability indices have been put to is the grouping of various species for commercial classification (Limaye : 1954), on which would be based the commercial preference of various species. These indices have also been made use of for actual selection of species for different uses (Limaye : 1944; Chaturvedi : 1955).

Working Stresses

The mechanical properties of timber, as derived in a laboratory on standard sizes of clear specimens, and their use for the evaluation of suitability indices have been discussed above. For convenience in designing timber structures, the strength values are to be adjusted to meet the conditions that may operate on the material in actual service when sued in structures. These adjusted values are known

as *working stresses,* and are derived by dividing the fundamental stresses (i.e., mechanical properties as determined in tests) by various factors relating to inherent variability, duration of loading, accidental loads, grade of the material, location of use, and sizes and shapes of the members, etc. A combination of all these factors is known as the *factor of safety.*

A product of factors relating to inherent variability, long-time loading effects, and accidental overloading are sometimes known as the *factor of ignorance.* In some countries, what is known as the *basic stress* of the material is obtained by dividing the fundamental stresses by the defined factor of ignorance. In fact, these basic stresses indicate working stresses for defect-free, straight-grained timber, for use in inside locations under normal atmospheric conditions. Apart from these, factors relating to the grade of timber, the location of its use, and the size and shape in which it is used should be considered for safe working stresses in timber designs; hence the *safe working stresses* are derived by dividing the basic stresses by these factors. Taking all these into consideration the final factors of safety applied to the various properties in deriving safe working stresses are given in Table No. X—6 for Standard Grade Structural No. 2 (explained in a later paragraph).

TABLE X—6

Total factors of safety applied to the various properties in deriving safe working stresses

Strength property	Standard Grade Structural No. 2		
	Inside locations	Outside locations	Wet location
Extreme fibre stress in beams for hardwoods (broad-leaved species)	5	6	7
Extreme fibre stress in beams for softwoods (conifers)	6	7	8.5
Shear along grain	7	7	7
Horizontal shear in beams	10	10	10
Maximum compressive stress along grain	4	4.5	5.5
Compressive stress across grain	1.75	2.25	2.75

In bending, the safety factors for coniferous species are slightly greater than those for hardwoods. This difference is based on a comparative study of data from tests on large structural beams and small clear specimens cut from the same material. It was found that the ratios of the strength of structural beams to that of small clear specimens were higher for hardwoods than the corresponding ratios for conifers. This is attributed to the incidence of defects such as knots, cross grain, etc., that affect the strength in bending in the case of conifers (Seaman : 1933).

No factor of safety is generally applied to Modulus of Elasticity. When, however, the Modulus of Elasticity is employed for computing the deflection of beams subjected to continuous heavy loading, which may often exceed the conventional elastic limit of the material, such as floor beams in warehouses, its value is reduced from 75 to 50 per cent of the fundamental value. It is also usual in such cases to use the average value of Modulus of Elasticity and limit the safe allowable deflection in the beams to 1/360 th of span in oridinary cases.

For purposes of stress grading, usually three grades are recognised in India and these have limitations of defects as discussed below.

The three grades are :

1. Select grade—Structural No. 1
2. Standard grade—Structural No. 2
3. Common grade—Structural No. 3

Taking the strength of clear timber in green condition as found by standard tests on small specimens as the basis, the *select grade* will contain defects which are estimated to reduce the fundamental stress by about 1/8th, the *standard grade* by about 1/4th, and the *common grade* by about 3/8th. In other words, material of select grade will have about 87½ per cent of fundamental strength, the standard grade about 75 per cent, and the common grade about 62½ per cent. Material containing greater defects than those allowed for common grade is not generally recommended where strength is an important factor. While it is not possible to assess exactly the cumulative effects of defects, which depend not only on sizes but also on their location in a piece of timber, it is commonly accepted that select grade structural No. 1 admits defects only half as large as those permitted in the standard grade, i.e., Structural No. 2, and the slope of grain is limited to 1 in 20. The safe working stresses for the select grade for bending, shear and compression are obtained by multiplying the working stresses of standard grade by 7/6. Common grade, i.e., structural No. 3, admits defects one and a half times as large as those permitted in the standard grade, and the slope of grain is limited to 1 in 12. The safe working stresses for the common grade for bending, shear and compression are obtained by multiplying the working stresses for the standard grade by 5/6. Table No. X—7 (pages 138-243) gives working stresses for standard grade material of a few selected species.

Important Factors Influencing Strength Properties

Apart from the fundamental biological aspects which influence the properties of wood, i.e., cell size, cell-wall thickness, their orientation and also the chemical composition of cell substances, there are a number of external causes which manifest their effect on the strength of wood. While the properties of wood have always been studied under ordinary laboratory conditions with the object of obtaining comparable and reproducible figures for general utilization purposes, the study of factors influencing the properties of wood has gained considerable attention only in the recent past, with the object mainly of standardisation and increased accuracy in evaluation of wood quality. In the present age of precision and use of wood under extreme conditions of weather and a variety of stresses, it has become all the more necessary that the factors influencing strength and the exact extent of their influence should be assessed very carefully. This has also been found useful for rational utilization of timber by prescribing proper safety factors for use in engineering designs and for stress-grading the material.

All the factors that influence the strength of the timber can broadly be classified into two groups : (1) Growth conditions of timber and their inherent characteristics over which there is no control at the time of evaluation of strength; and (2) External factors for which there can be a control at the time of evaluation of strength. The second group can be further divided broadly into two sub-groups, viz., (i) those factors depending on the condition of material at the time of selection; and (ii) those depending on the methods of test. All the factors found influencing the strength of wood are discussed below, with particular reference to the work done in this field in this country.

Factors depending on growth conditions and inherent characteristics

The natural structure of wood is primarily designed to serve the functional needs of living plants, growing in different localities and environmental conditions. Hence the pattern of the structure, and consequently the properties, differ not only according to the genus and species of the tree but also according to the environmental conditions of growth. The variation in mechanical properties is so markedly wide that it is not economically feasible to investigate all conditions of growth and environment for all the species. But wherever a few studies have been made, they have been made either on the basis of test data on defect-free small clear specimens under comparable conditions of test or on the basis of experience gained in the long continued use of material from different regions. Results obtained through some of the above studies are briefly discussed in the following paragraphs.

Soil, climate and locality.—The environmental factors concerning the trees, such as elevation, air temperature, solar radiation, humidity, precipitation, soil characteristics, growing space and geographical distribution, can no doubt be expected to influence the properties of the wood, but, by and large, only empirical ideas exist as a result of experience of users over long continued periods. For example, small differences are commercially recognised between Malabar coast teak and central

India teak, and similarly between Uttar Pradesh sal and Madhya Pradesh sal. Not unoften such differences are over-emphasised in commercial fields although they are not of statistical significance. Sometimes, significant differences that can distinguish statistically classified groups on the basisof mechanical properties have not accorded with the geographical congruity or continuity of the forests (Nair and Mukherji : 1957/60). In a general way these factors are of practical importance only so far as they may affect the apparent density of the material, which in turn reflects its strength in a broad sense. In all such cases, correlations can be more easily worked out with other mechanical and physical characteristics of the wood of trees grown under different environments rather than directly with any quantitative factors of environments themselves. In Germany a theory, known as "nourishment theory" (Ernahrungh Theorie), was evolved by Robert Harting (1901), according to which wood density would depend on the inter-relation between soil fertility, transpiration, and assimilation. The density of the wood is claimed to be influenced by the ratio of the amount of conducting tissue to that of supporting tissue and their relative pressure areas. Paul (1930) has made some detailed studies on these aspects and has come to the conclusion that severe crowding in the case of broad-leaved trees results in a decrease of specific gravity, and that thinning shows an increase in the specific gravity. He has however recommended that, for the properties to be uniform and the material to have fewer defects, the trees should be grown sufficiently close while young and later thinned properly to maintain a steady diameter growth. In conifers, in the early years, the crown, whose development depends on the spacing between trees, appears to be a principal factor in determining the specific gravity. If the soil moisture and soil fertility are such that the tree continues to grow throughout the vegetative season, a higher specific gravity is obtained. Some types of soil with a zinc content are also reported to yield wood of higher specific gravity.

Age of the tree.—While it is not possible to enumerate any general principles on the effect of the age of the tree on the strength properties of the timber, studies in the U. S. A. have shown that coniferous trees of 25 to 35 years have shown lower density and strength properties than older trees. The age at which mechanical maturity is attained would obviously vary with species, e.g., 50 years in teak (Sekhar : 1962). In the case of bamboos, some take 4 to 5 years to attain mechanical maturity (Sekhar, Rawat and Bhartari : 1962). Some current studies on eucalypts in India, up to the age of 8 years, indicate that strength and specific gravity increase with age.

Position of wood in the tree.—Several studies have been in progress both in India and abroad about the influence of the position of wood in a tree on the strength properties of wood. It was observed that in most cases the strength initially increases from pith to periphery and then decreases again near the end. The strongest timber is thus in a zone intermediate between the pith and the periphery. Studies of the variation of strength from bottom to top of the tree were made on teak (Sekhar and Negi : 1966), and it was concluded that the strength is generally higher at bottom and top regions and comparatively lower at intermediate heights. The height of minimum strength in teak trees was found to be somewhere between 5 and 8 metres from the bottom of the tree. Some interesting studies have proved that the strength of wood in the branches is slightly higher than that in the trunk, which in turn is slightly higher than the strength of the root wood. Although there is difference in colour between heartwood and sapwood in many species, contrary to the common belief there is no appreciable difference in their strength.

Rate of growth.—Some studies on teak by Limaye (1942) revealed that the trees growing at the rate of 4 to 5 mm in radius per year produce the strongest timber. However, from later studies Nair and Mukerji (1957/60) have claimed that the rate of growth has no appreciable effect on the strength of wood. In other countries also, some correlation between density and rate of growth has been observed, but it is generally felt that the importance of the relation is sometimes over-emphasised, and therefore, rate of growth is not always taken as a factor influencing the strength of the material. In fact the relative proportion of early wood and late wood, as also the growth history of the tree, should be expected to play a more significant role than merely the width of the annual ring as measured in the cross-section of the timber.

(Contd. on page 144)

TABLE

Working stresses for some

[Source : Code of Practice for use of structural timber in Building

Sl. No.	Species	Average Unit weight at 12 % Moisture content (kg per m³)	All-Grades Modulus of Elasticity in tonnes per cm² in all locations	Working		
				Bending and Tension along grain		
				Extreme Fibre Stress		
				Inside location	Outside location	Wet location
1	2	3	4	5	6	7
1.	*Abies pindrow*	465	94	78	66	56
2.	*Acacia nilotica* syn. *A. arabica*	835	108	182	154	124
3.	*Acrocarpus fraxinifolius*	690	126	162	134	108
4.	*Adina cordifolia*	675	91	138	112	92
5.	*Albizia lebbeck*	640	112	134	112	88
6.	*Albizia odoratissima*	735	136	186	154	126
7.	*Albizia procera*	655	90	134	112	88
8.	*Altingia excelsa*	800	114	172	144	116
9.	*Amoora* spp.	675	105	134	112	92
10.	*Anogeissus latifolia*	930	114	168	140	112
11.	*Artocarpus chaplasha*	515	91	130	108	88
12.	*Artocarpus heterophyllus*	595	82	126	106	84
13.	*Artocarpus hirsuta*	595	105	152	126	102
14.	*Bridelia retusa*	575	94	116	98	78
15.	*Calophyllum* spp.	640	96	134	108	88
16.	*Canarium strictum*	655	119	134	112	88
17.	*Carallia brachiata*	755	126	182	154	124
18.	*Castanopsis* spp.	625	98	106	88	70
19.	*Casuarina equisetifolia*	765	115	148	124	98
20.	*Cedrus deodara*	560	95	102	88	70
21.	*Chukrasia tabularis*	675	140	124	98	78
22.	*Chloroxylon swietenia*	1,010	116	176	148	120
23.	*Cullenia rosayroana*	625	124	148	124	98
24.	*Cupressus torulosa*	515	84	88	78	64
25.	*Cynometra polyandra*	895	132	190	158	126
26.	*Dalbergia latifolia*	755	93	168	140	112
27.	*Dalbergia sissoo*	770	89	152	126	102
28.	*Dillenia* spp.	640	81	120	98	80

X– 7

selected species

[(Material, Grading and Design) (Revised) IS : 883-1961]

stress in kg/cm² for Standard Grade

Shear		Compression					
Horizontal	Along grain	Parallel to grain			Perpendicular to grain		
All locations	All locations	Inside location	Outside location	Wet location	Inside location	Outside location	Wet location
8	9	10	11	12	13	14	15
6.0	8.4	60	52	42	16.0	12.5	10.5
15.4	22.2	112	102	80	65.5	50.5	41.5
12.4	17.6	106	94	78	45.5	36.0	29.5
9.4	13.4	84	74	64	36.5	28.0	23.0
10.8	15.4	88	80	66	44.5	34.5	28.0
15.4	21.8	134	120	94	72.5	56.0	46.5
9.8	14.0	84	78	64	43.0	33.5	27.5
11.6	16.6	108	98	80	68.0	53.5	43.5
9.2	13.0	84	74	60	37.5	29.0	24.0
11.6	16.6	94	84	70	55.5	43.0	35.0
8.4	12.4	84	74	64	36.5	28.0	23.0
10.2	14.4	84	74	60	46.5	36.0	29.5
7.4	10.6	102	92	74	33.0	26.0	21.0
8.8	12.6	70	64	52	40.0	31.5	26.0
9.2	13.0	88	78	64	33.0	26.0	21.0
8.4	12.4	80	74	60	28.0	22.0	17.5
12.4	17.2	112	102	84	60.0	46.5	38.0
8.0	11.6	64	56	46	26.5	20.5	17.0
12.6	18.0	80	74	60	39.5	31.0	25.0
7.0	10.2	78	70	56	28.5	21.0	17.0
10.6	15.2	70	64	52	39.5	31.0	25.5
13.8	19.6	116	102	84	67.5	52.5	43.0
6.4	9.2	92	80	66	26.5	20.5	17.0
5.6	8.0	70	64	50	23.0	18.5	15.0
12.6	18.2	116	102	84	57.0	44.5	36.0
11.6	16.6	106	92	78	64.5	50.5	41.5
11.6	16.8	94	84	66	46.5	36.0	29.5
8.8	12.6	74	64	52	31.0	24.0	19.5

(*Contd.*)

TABLE

1	2	3	4	5	6	7
29.	*Dipterocarpus* spp.	755	127	104	120	94
30.	*Dysoxylum malabaricum*	735	109	134	108	88
31.	*Elaeocarpus tuberculatus*	465	87	98	80	64
33.	*Eucalyptus eugenioides*	850	115	166	138	108
33.	*Eugenia* spp.	850	112	152	126	102
34.	*Garuga pinnata*	575	76	116	98	78
35.	*Gmelina arborea*	495	75	98	80	66
36.	*Grewia tiliaefolia*	785	148	182	152	124
37.	*Grewia vestita*	755	120	154	130	102
38.	*Heritiera* spp.	960	136	172	144	116
39.	*Heterophragma roxburghii*	610	87	124	102	80
40.	*Holoptelea integrifolia*	595	75	120	98	80
41.	*Hopea glabra* and *H. parviflora*	1,010	139	200	166	134
42.	*Hopea utilis*	995	169	250	208	168
43.	*Juglans* spp.	575	91	116	94	78
44.	*Kayea floribunda*	815	109	168	140	112
45.	*Kingiodendron pinnatum*	610	106	134	108	88
46.	*Lagerstroemia speciosa* and *L. hypoleuca*	640	88	12	102	80
47.	*Lagerstroemia lanceolata*	675	110	138	112	92
48.	*Lagerstroemia parviflora*	735	110	144	120	94
49.	*Lophopetalum wightianum*	465	73	84	70	56
50.	*Machilus macrantha*	515	77	102	84	66
51.	*Machilus odoratissima*	690	100	124	102	80
52.	*Mangifera indica*	655	91	124	102	80
53.	*Manilkara littoralis*	1,105	174	228	190	152
54.	*Mesua ferrea*	960	163	232	194	154
55.	*Michelia* spp.	495	89	102	84	66
56.	*Miliusa tomentosa*	735	110	148	124	98
57.	*Mimusops elengi*	880	124	172	144	116
58.	*Ougeinia oojeinensis*	865	86	134	112	88
59.	*Palaquium ellipticum* and *P. polyanthum*	675	115	144	120	94
60.	*Phoebe* spp.	545	86	116	94	78
61.	*Picea smithiana*	480	92	78	66	52
62.	*Pinus radiata*	625	109	84	70	60
63.	*Pinus roxburghii*	575	98	84	70	60
64.	*Pinus wallichiana*	515	68	66	56	50

X—7 (*Contd.*)

8	9	10	11	12	13	14	15
8.0	11.6	88	78	64	31.0	24.0	19.5
9.8	14.0	80	70	56	30.0	24.0	19.5
7.0	9.8	64	56	46	19.5	15.5	12.5
12.4	17.2	112	102	80	76.0	59.0	48.5
11.6	16.6	92	84	66	57.5	45.0	36.5
10.2	14.4	74	64	52	33.5	26.0	21.0
7.8	11.2	56	50	42	34.5	26.5	22.0
13.0	18.6	120	106	88	60.0	46.5	38.0
13.8	19.6	92	80	66	41.5	32.5	26.0
12.6	15.8	106	94	78	72.5	56.0	45.5
6.6	9.4	78	70	56	33.5	26.0	21.0
8.8	12.6	66	60	50	28.0	22.0	17.5
14.0	20.0	138	124	102	97.0	75.0	62.0
15.2	21.4	166	148	120	93.5	72.5	60.0
8.4	12.0	66	60	50	23.0	18.5	15.0
10.8	15.8	102	88	74	44.5	34.5	28.0
8.8	12.6	80	74	60	29.0	22.5	18.0
8.4	12.0	78	66	56	41.5	32.5	26.5
9.2	13.0	88	78	64	41.5	32.5	26.0
10.8	15.4	88	78	64	37.0	29.0	24.0
6.0	8.4	52	46	38	17.5	14.0	11.0
7.0	10.2	64	56	46	24.0	19.0	15.5
10.2	14.8	80	74	60	35.0	27.5	22.5
9.4	13.8	74	66	52	31.0	24.0	19.5
14.8	21.0	144	126	102	112.5	88.0	71.5
12.4	17.6	154	138	112	58.5	45.5	37.5
6.6	9.8	64	56	46	22.5	17.5	14.0
9.2	13.4	98	84	70	34.5	26.5	22.0
12.6	18.0	108	98	80	55.5	43.5	35.0
12.0	17.2	84	74	64	50.5	39.5	32.5
9.2	13.0	92	80	66	38.0	29.5	24.5
7.8	11.2	78	66	56	24.5	19.0	15.5
6.0	8.4	56	50	42	17.0	13.5	10.5
7.0	10.2	64	56	46	22.0	17.0	14.0
6.4	9.2	64	56	46	22.5	17.5	14.0
5.6	8.0	52	46	38	17.0	13.5	10.5

(*Contd.*)

TABLE

1	2	3	4	5	6	7
65.	*Planchonta andamanica*	915	131	162	134	108
66.	*Poeciloneuron indicum*	1,135	163	216	186	152
67.	*Polyalthia fregrans*	515	92	108	92	70
68.	*Pongamia pinna.a*	755	91	120	98	80
69.	*Prerospermum acerifoliu*	610	96	138	112	92
70.	*Pterocarpus dalbergioides*	720	112	172	144	112
71.	*Pterocarpus marsuplum*	800	103	148	124	98
72.	*Quercus spp.*	865	125	148	124	98
73.	*Schima wallichii*	690	96	112	92	74
74.	*Shorea assamica*	545	93	112	92	74
75.	*Shorea robusta*	800	127	168	140	112
76.	*Stereospermum personatum*	735	129	190	158	126
77.	*Tectona grandis*	625	96	140	116	94
78.	*Terminalla biaiata*	690	124	154	130	102
79.	*Terminalia manii*	835	127	168	140	112
80.	*Terminalia myriocarpa*	610	96	120	98	80
81.	*Terminalia paniculata*	785	132	168	140	112
82.	*Terminalia procera*	625	90	118	98	78
83.	*Terminaiia tomentosa*	880	111	154	130	102
84.	*Vateria indica*	575	110	116	94	78
85.	*Vitex alrissima*	930	130	182	152	120
86,	*Xylia xylocarpa*	835	117	162	138	108

X—7 Concld.

8	9	10	11	12	13	14	15
9.4	13.8	108	94	78	49.0	38.5	31.5
15.2	21.8	148	130	106	87.0	67.5	55.5
7.0	10.2	70	64	50	17.0	13.5	10.5
8.4	12.0	66	60	50	30.0	23.0	19.0
8.4	12.4	88	78	64	31.5	24.5	20.5
10.2	14.4	120	106	88	55.0	43.0	35.0
9.4	13.4	92	80	66	41.0	31.5	26.0
12.0	16.8	92	80	66	45.5	35.0	29.0
8.8	12.6	66	60	50	22.5	17.5	14.0
9.2	13.0	70	64	52	29.0	22.5	18.5
9.4	13.4	106	94	78	45.5	35.0	29.0
11.2	15.8	120	106	88	40.0	31.0	25.5
9.8	14.0	88	78	64	40.0	31.0	25.5
8.8	12.4	98	88	70	36.0	27.5	22.5
11.2	15.8	102	92	74	51.5	39.5	32.5
8.4	12.0	78	66	60	29.0	22.5	18.5
9.2	13.0	108	102	80	45.5	35.0	29.0
8.8	12.6	72	64	52	30.0	23.0	19.0
10.2	14.8	94	84	70	55.0	42.0	34.5
7.4	10.6	74	66	56	22.5	17.5	15.0
11.6	16.6	126	112	92	95.5	74.5	60.5
12.6	18.2	108	98	80	77.5	60.5	49.0

Season of felling the tree.—A theory is frequetly advanced that the timber felled in winter months has generally greater durability, less refractoriness, better colour and even increased strength. This theory is however not substantiated by actual investigations, although it is recognised that the climatic differences during the various seasons may have some effect on subsequent seasoning and the development of seasoning defects. The theories of sap movement and sap composion during various seasons of the year have not always taken into consideration the development of growth stresses, also influenced by the presence of moisture and changes in temperature. Hence, as a general conclusion it may be stated that, if trees felled at various times during the year are immediately converted and kiln-seasoned in exactly the same schedule, no difference in strength due to season of felling may be expected,

Natural and plantation grown trees.—Studies to investigate possible differences in the strength of natural and plantation grown trees of the same species were made in India by Person (1911/1913), Limaye (1942), Sekhar and others (1960/1966), for the reason that in some large consuming cetres a Prefeienec is always expressed for natural grown timber as against that grown in plantations. Detailed investigations have, howevr, shown that no significant differences exist between the two, though in some localities natural grown teak has shown some superiority to plantation grown teak, while in others the reverse has been found to be the case.

Live versns dead timber.—In some specifications for purchase of timber, there are stipulations that material trom trees that have died due to fire or biological causes will not be accepted even though it may be otherwise sound. There does not seem to exist any scientific foundations for such a prejudice, but it is recognised that trees left standing too long after being dead may seriously deteriorate due to weather condions or insect and fungus attack. Such a situation arises even in logs from living trees, unattended to for long periods. Hence, it may be concluded that, if the swan material is otherwise sound, irrespective of the fact whether it comes from a living tree or a dead one, no difference exists in the strength under identical conditions of testing.

Natural twist in trees.—Natural twist, otherwise known as *Spiral Grain*, is one of the common timber defects reducing the strength of the material. The twist may be either left-handed or right-handed, and in a given tree it may vary in degree and direction from the pith to the periphery and at different heights of the bole also. Several theories exist as to the cause of this type of grain, and there is evidence to show that the defect could be hereditary. Sometimes the defects cannot be detected by casual inspection of the external surface of timber, and sometimes this may also be confused with other types of inclined and diagonal grain that one may come across in converted timber. Spiral grain is a serious defect and may cause the twisting of a piece. Some investigations on twisted and untwisted chir in India be Sekhar Sharma (1964) have shown that the strength rapidly decreases with the increase of the angle of twist from 0° to 30° but thereafter remain steady at the minimum value. An empirical formula given below was found to fit the case qusie closely :

$$\log S_\theta = \log S - k \tan^n \theta$$

Where,

S_θ = strength of timber in spiral-grained tree;

S = strength in straight grain timber;

θ = angle of twist expressed in degree in the range of 0° to 30°, i.e., the angle which the fibre makes with axis of the trunk; and

'k' and 'n' are constant, varying according to species and strength propertses.

Specific gravity.— The influence of specific gravity on the strength of timber is so highly manifasted that sometimes, in the absence of available data of strength figures for some species, the specific gravity itself is taken as a measure of strength. Sekhar and Rawat (1959) have studied the data for nearly 140 species and established the relation ;

$$S = k\rho^n$$

(Contd. on page 146)

TABLE X—8

Effect of specific gravity on strength of timbers

	Property	Unit	Green condition	Air Dry condition
Static Bending	Fibre stress at E.L.	kg/sq cm	682ρ	865ρ
	Modulus of rupture	kg/sq cm	1153ρ	1495ρ
	Work to Elastic Limit	kg-cm/cu cm	$0.183\rho^{1.25}$	0.239ρ
	Work to Max. Load	kg-cm/cu cm	1.05ρ	1.20ρ
	Total work	kg-cm/cu cm	$3.5\rho^{1.5}$	$3.6\rho^{1.75}$
	Modulus of Elasticity	1,000 kg/sq cm	165.9ρ	194.8ρ
Impact Bending	Fibre stress at E.L.	kg/sq cm	1665ρ	1853ρ
	Work to Elastic Limit	kg-cm/cu cm	$0.773\rho^{1.25}$	0.696ρ
	Height of Drop	cm	$163\rho^{1.25}$	$140\rho^{1.25}$
	Modulus of Elasticity	1,000 kg/sq cm	236.9ρ	270ρ
Comp. parallel to grain	Comp. stress at E.L.	kg/sq cm	414ρ	$464\rho^{0.75}$
	Max. crushing strength	kg/sq cm	579ρ	825ρ
	Modulus of Elasticity	1,000 kg/sq cm	185.8ρ	209.2ρ
Comp. perp. to grain	Comp. stress at E.L.	kg/sq cm	$176\rho^{1.75}$	$191\rho^{1.5}$
Hardness	End	Load in kg to embed 1.128 cm dia. ball to half dia.	$1232\rho^{1.75}$	$1490\rho^{1.75}$
	Radial		$1376\rho^{2}$	$1669\rho^{2.25}$
	Tangential		$1211\rho^{1.75}$	$1524\rho^{2}$
Shear	Radial	kg/sq cm	135ρ	161.7ρ
	Tangential	kg/sq cm	151.2ρ	175.8ρ
Tension perp. to grain	Radial	kg/sq cm	66.4ρ	$53.1\rho^{0.75}$
	Tangential	kg/sq cm	2.3ρ	75.9ρ

ρ=Specific gravity based on weight (oven dry) and volume (at test).

Where,

S = strength;

ρ = Standard specific gravity i.e., based on oven-dry weight and volume at test; and

'k' and 'n' are constants.

In many cases the value of 'n' works out to unity, thus indicating that there is a linear relationship between strength and specific gravity. Table No. X—8 (page 145) indicates the values of 'k' and 'n' for the various properties.

It may be seen from the formulae that all properties do not vary with specific gravity in the same manner. While one piece of wood that has twice the density of the second may be expected to have also twice its capacity when required for a beam or a post, it would nearly be 2½ times for tools handles, etc., where shocks come into play; in hardness and abrasive resistance it could as well be 3½ times. The relations indicated in Table No. X—8 are obtained from the averages for many different species. Within the range of any single species the rate of change in strength with change in specific gravity is governed by the following formula :

$$\frac{S}{S'} = \left(\frac{\rho_s}{\rho_s'}\right)^q$$

Where,

S = strength corresponding to specific gravity ρ_s of a given species;

S' = strength corresponding to specific gravity ρ_s' of the same species ; and

'q' is the constant of the equation.

The values of 'q' for various properties have not been worked out for Indian species but those done in U.S.A. are given in Table No. X—9.

TABLE X—9

*Effect of variation in specific gravity on strength properties within the range of a particular species**

Property	q†
STATIC BENDING	
Fibre stress at E.L.	1.50
Modulus of Rupture	1.50
Modulus of Elasticity	1.25
Work to Max. Load	2.00
Total work	2.25
IMPACT BENDING	
Fibre stress at E.L.	1.50
Modulus of Elasticity	1.25
Height of Drop	2.00
COMPRESSION PARALLEL TO GRAIN	
Fibre stress at E.L.	1.25
Max. crushing strength	1.25
Modulus of Elasticity	1.25
COMPRESSION PERPENDICULAR TO GRAIN	
Fibre stress at E.L.	2.50
HARDNESS	
End, Radial, Tangential	2.50

*From Forest Products Laboratory, Design of Wood Aircraft Structures, *ANC, Bull.*18; Army-Navy-Civil Comm. on Aircraft Design Criteria, Aero. Board, Washington, 1944.

†q=Exponent used in the equation $\frac{S}{S'} = \left(\frac{\rho_s}{\rho_s'}\right)^q$

Other growth factors.—In addition to the above mentioned factors, there are numerous others such as distortions or abnormalities in growth rings, pitch pockets, gum spots, mineral streaks, etc. Their direct effects on strength are to be considered practically from the abrupt changes they cause in the structure or growth rings. These may reduce areas of stress concentration and consequent checks and shakes in the material.

Influence of external factors on strength of timbers

These external factors arise only at the time of testing the wood and can be controlled as desired. They can be broadly classified into two groups : (1) those depending upon the condition of material and (2) those depending upon conditions of testing. In the standard methods of evaluation of strength properties of various species, these conditions are defined as accurately as possible and necessary clauses provided in the testing specifications so as to have specified conditions and obtain comparable data on all species tested.

Factors depending on condition of material at the time of testing.—These are the factors which define the moisture content, the temperature, the defects, and the preservatory treatment. Most of the standard testing is done in the "green condition" of the timber, i.e., well above the fibre saturation point, and also at 12% moisture content at the room temperature on defect-free specimens, known as "small clear specimens". However, a knowledge of variations due to these factors would be useful for adjusting the strength figures whenever the material is tested with slightly different set of conditions. These effects are briefly discussed below.

(1) *Moisture content.*—Strength of the timber above the fibre saturation point does not show any significant variation, but below the fibre saturation point, as the walls of the individual cells become more and more dry the strength increases, and the relationship is given by the formula :

$$S = 10^{a-bm}$$

where 'a' and 'b' are the constants, 'S' is the strength, and 'm' is the moisture content. From the above equation it can be deduced that if 'S_f', is the strength property of the wood at and above the fibre saturation point 'f', and 'S_m' is the strength at moisture content 'm', then

$$\log S_m = \log S_b + b\,(f—m)$$

Where after actual testing and computation the strength in the green condition 'S_f' is known and strength 'S_m' in dry condition is also known, then the value of 'b' in the above equation can be evaluated and substituted in a similar equation to the find out the strength at any other required moisture content m', say, 12% as in standard evaluation. It may be noted that 'b' will not be the same for all properties in the species. The increase in strength per 1% decrease in moisture below the fibre saturation point varies from -0.5 to 8%, i.e., in some species in some cases, like the height of drop in the impact-bending test and work-to-maximum load in static bending, there is actually a decrease in strength value. At this stage, it should also be borne in mind that the effect of increase in strength in drying, although quite marked in small clear specimens may be entirely offset in larger pieces by the incidence of checks and other defects during the process of drying.

(2) *Temperature.*—The effect of temperature on strength properties may be either temporary or permanent. The temporary effects are those that are actually observed at the time the concerned temperature is attained. Permanent effects are those that are retained even after the material has been restored to normal temperatures. These effects naturally depend on not only the temperature attained but also the duration for which the material remained under that temperature. Several investigators have studied the temporary influence of temperature but comparatively few the permanent effects. Most strength properties decrease at temperatures above the normal room temperature and increase at reduced temperatures more or less linearly. The variation has also been shown to be dependent on specific gravity, moisture content and type of stress. Sekhar and Sharma (1955) have not only shown the occurrence of a slight increase of impact values with increase of temperature of green specimens linearly but have also indicated the possibility of a maximum value being reached between 70° and 90° C. Studying the effect of temperature in green condition in bending and compression, Sekhar and Gupte (1965) have found that properties like fibre stress at proportional limit, modulus of rupture, and maximum crushing stress decrease linearly with increase of temperature from 0° to 70° C, but that work-to-proportional limit decreases exponentially. Studying the rate of decrease in strength properties per

unit temperature with reference to specific gravity, they found that, with increase of specific gravity, this rate increases exponentially in the case of bending but linearly in the case of compression. They have also pointed out that the conventional proportional limit of elasticity decreases with increase in temperature.

(3) *Preservative treatment.*—Several investigations have been made from time to time to determine the effect of various methods of preservative treatment and various commercial preservatives. While it is generally believed that there is no variation in strength due to preservatives, the methods of preservation, such as under high temperatures or high pressures, may slightly weaken the material, particularly under impact. Some of these investigations suggest that most of the preservative chemicals may not affect the strength of cells of the wood, but the presence of any deposited salts between the cells may sometimes make the material brittle under impact. Some woods which have high resistance to treatment may require a pretreatment, such as incising or steaming under pressure, boiling under vacuum, etc., which may slightly reduce the strength of the wood.

(4) *Defects.*—It is well known that all defects do not affect the strength properties to the same extent and that the same defect does not reduce the strength to the same extent at all positions in the stressed member. Hence, in the normal grading systems the permissible defects are generally mentioned not only in terms of their sizes and numbers but also in terms of the location of the defects in the timber piece intended for specific use. It may be mentioned at this stage that it is also not convenient to evaluate mathematically the exact cumulative effect of all the defects simultaneously. Hence the total number of different types of defects permitted on any material under a given specification is more or less empirically based on experience, or sometimes on the maximum effect which any single permissible defect may cause. In the following paragraphs the effects of some of the important defects are briefly summarised.

(a) *Grain angle.*—If the direction of stress made with the direction of the fibres is neither 0° nor 90° but, say, θ, then the strength at the given "grain angle" θ is given by the formula :

$$S = \frac{S_0 \times S_{90}}{S_0 \text{Sin}^2\theta + S_{90} \text{Cos}^2\theta}$$

where S_0 and S_{90} are the respective strengths along and across the fibres. It is well known that the strength in 0° direction is the highest and that in the 90° direction the lowest. The nature of above equation indicates that the strength rapidly decreases up to about 30°—40° and thereafter the rate of decrease is comparatively slow. Hence, the following are the recommended limiting ratios for use of timber in structures :

(i)	Compressive strength	1 in 10
(ii)	Modulus of elasticity	1 in 15
(iii)	Modulus of rupture	1 in 20
(iv)	Shock resistance	1 in 25

(b) *Knots.*—The position of knots in a beam is more important than their size, as the weakening effect is greater in tension than in compression. Hence the size and shape of the knots are generally prescribed differently for different locations in the different grades of timber. In evaluating the cumulative effect of knots, usually the sum of diameters is taken into consideration and their limits at various portions of the members are prescribed.

(c) *Checks, shakes and splits.*—These reduce the resistance to shear almost directly in proportion to the size. However, in prescribing their permissible limits under any specification, usually the estimated area of separated surfaces at the place of defect expressed as a percentage of the total area in that plane in the material is taken for consideration, but the limits of the defects are quantitatively expressed only in terms of one or more of length, with and depth of the checks and shakes.

(d) *Pith or boxed heart.*—The presence of pith is not considered as a defect that reduces the strength, but checks, shakes, and softness (as compared to neighbouring portions) are to be duly taken into consideration at the time of selection of material for uses where stress comes into play.

(e) *Decay and sapstain.*—Decay due to various types of fungal attacks would naturally affect the strength of timber, as the cell walls are usually broken down. In the early or incipient stages of

decay, pronounced brashness or brittleness may usually appear and the infected material may trend to break suddenly under stress. In the advanced stage of this defect the strength of wood may be considerably reduced, particularly in shock-resisting ability. Sapstaining fungi, however, do not usually decrease the strength so much as to make the wood unfit for ordinary commercial use except in respect of toughness.

Factors depending upon conditions of testing.—It is now well recognised that the variations in strength properties of timber are due not only to growth conditions and condition of the material at the time of test but also to methods of testing and computations of the data. For this reason, several specifications and standards prescribe the rate and direction of loading and the size and shape of testing material for the different types of stresses. While most of the tests in many laboratories of the world were being conducted on the mechanical type of machines in the earlier years, the recent trend is generally to use the hydraulic type of machines. Strength also appears to be slightly different when tested on the two different types of machines, because the type of control for the operation is slightly different in the two types. In the hydraulic type the "rate of loading" is controlled by the rate of stress or applied load, and in the mechanical types this rate is controlled by the rate of strain or deformation. The various factors which are encountered during such tests, and have a bearing on the final value of strength, are discussed below :

(1) *Rate of loading.*—Wood is considered to be an elastoplastic material, i. e., from the point of view of mechanics its structure consist of elastic elements and plastic elemects. Hence under a given type and duration of stress the two elements are bound to behave differently and consequently the static strength of the material is affected to some extent. The rate of loading is considered either in terms of the rate of fibre strain (as in the case of the mechanical type of machine) or in terms of the observed rate of application of load (as in the case of the hydraulic type of machine). The following are the formulae used for the speed of movable heads of the mahchine :

$N=ZL$ for compression or tension, and

$$N=\frac{ZL^2}{Kd} \quad \text{for bending of beams;}$$

Where,

N = rate of movable head of machine in inches or cm per minute;
L = span of the beam or length of tension or compression specimens in inches or cm;
d = depth of the beam;
Z = rate of fibre strain per unit length of fibre (in inches or cm per minute); and
K = a factor depending upon type of loading for the bending of the beam.

The values commonly used for ' ' and 'K' are as follows :

for central loading	K = 6;
for two point loading (also known as third point loading)	K = 5;
for bending of large beams	Z = 0.0007;
for bending of small beams and compression of large specimens	Z = 0.0015; and
for compression of small specimens	Z = 0.003

Although it is observed that with an increase in the rate of loading there is generally an increase in the strength properties, an increase in speed of about 50 per cent increases the value of the static strength by about 2-3 per cent only. Hence, though in most specifications the rate of loading is prescribed in terms of the sizes of the specimens, in actual practice any deviation in speed up to 25 per cent from that specified for any given test is permitted.

(2) *Direction of loading.*—Due to the orthotropic nature of the material and the presence of radial rays in the structure, the direction of application of the load with reference to the principal axes

of symmetry in the material has a bearing on the strength properties of timber. Hence, in most of the standards, the surface on which the load is to be applied is prescribed. Some studies have been made in this country. Sekhar and Rajput (1965) reported the effects of load in the radial and tangential planes on properties like compression, sheer and tension perpendicular to grain. The strength in the tangential direction or plane is, in general, higher than that in the radial direction or plane.

(3) *Type of stress.*—Wood has shown different strength values under different types of stresses. Under dynamic stresses it has nearly twice the strength as indicated under static stresses. Hence, in designs of wooden structural members, no adjustment of working stresses is made for suddenly applied loads as is the practice in the case of other materials of construction. Even under different types of static loads, wood exhibits the greatest strength in tension parallel to grain and the least in tension perpendicular to grain. The strength in bending is somewhat intermediate between strength in tension and strength in compression.

(4) *Size and shade of the specimens.*—As a result of the influence on strength of the size and shape of the test specimens, specifications in different countries have prescribed definite ratios of cross-sectional dimensions to the lengths of the test specimens. In India, the effect of span-depth ratio in static bending was studied by Sekhar and Rawat (1958) and it was observed that both modulus of elasticity and modulus of rupture change with the span-depth ratio 'R' in the form of 'KR^n',

Where, n = 0.1 for modulus of rupture and 0.22 for modulus of elasticity, and

K = a constant which is different for different species.

In dynamic experiments the modulus of elasticity obtains its minimum somewhere between the ratio of 10 and 14. Studying on sizes of specimens in compression perpendicular to grain Sekhar and Rajput (1965) indicated that tests made on larger specimens of 5 cm × 5 cm × 15 cm gave higher figures than hose made on cubes of 5 cm × 5 cm × 5 cm.

(5) *Notches in the test specimens.*—A notch in the test specimen plays the role of concentrating stresses at desired parts in the specimens so that failures may be localised. Thus it affects the strength properties of wood. The ratio of stress in notched specimens to the stress in unnotched specimens is known as notch factor and the reciprocal of this is known as notch-sensitivity. Sekhar and Negi (1955-57) studied the effect of different types of notches in Izod-impact specimens on about 140 species and observed that most uniform and consistent results were obtained with a key-hole notch at the gripping place. The effect of notch in compression tests was studied by Sekhar and Rawat (1958) by taking internal and external notches of circular, oval, square and rectangular shapes for a few species. In all these cases the notch factors ranged from 0.7 to 1.1. A detailed comparison of shearing stress in a rectangular specimen and a specimen with a corner notch was made by Sekhar and Rajput (1965) and a very high correlation of the order of 0.9 was recorded, establishing a linear relationship between the two. In general, the shear values for specimens without notches was found to be 5 to 15 per cent higher than those for notched specimens. Thus, it is apparent that the effect of notches in wood is important and requires more exhaustive study, not only from the point of view of the fixing the standard sizes and shapes of test specimens but also from the point of view of actual use of the material for various purposes and general mechanics of the material.

It will be seen from the above paragraphs that the sources of variation in strength properties of timber are quite many as compared to those of other industrial and engineering materials. Even under situation where wood has been considered quite superior and has established its reputation in many respects, it has occasionally failed in competition. This can be attributed, at least in part, to wrong inspection and utilization of wood for various specific purposes and inadequate understanding of the causes, of variations in the material. With the increased knowledge of these variations, even though they may not be significant in many cases, more economic and successful utilization can be expected through suitable selection of the stock.

Typical Failures in Timber under Different Types of Stresses

The various types of failures that occur and develop in timbers are characteristic of not only the way in which the fibres are aligned in a member but also the stresses due to which they occur. Since the tensile strength parallel to grain of wood is greater than the compressive strength in the same

direction, and as the latter, in turn, is greater than strength in shear or compression perpendicular to grain, a beam should be normally expected to fail first by compressive forces or shear and then by tensile forces on the convex side of the bent beam, unless specific precautions are taken in the design. The effect of interlocking in fibres has also been found in specimens that failed due to shear and tension perpendicular to grain. The effect of shear would sometimes become visible in failure of the material under tension parallel to grain. What is normally a tough material under static forces would sometimes show characteristics of brittleness under dynamic forces. From all such observations, it is considered useful and necessary that in all the standard tests on timber a record of failures of test specimens is kept at the end of each test. From the nature of failure observed it would also be possible to assess whether or not the correct type of intended stresses have come to act on the member under rtest, and whether the data obtained on these specmiens is to be accepted or rejected for purposes of further computations. A brief description of some types of typical failures is discussed below.

Failures under bending stresses

Fig.X—6 indicates the typical failures that occur in members under bending forces. Their appearance, formation and development on the different sides of a beam and their general classification are briefly discussed below.

(i) *Simple tension.*—This is indicated in Fig. X—6 (a) and commonly occurs in straight-grained beams, particularly when the wood is in a dry condition. The failure is indicated by the fibres directly pulling apart on the external convex side and following paths of least resistance along the fibres on both sides of the location where the failure had initially occurred.

(ii) *Cross-grained tenstion.*—The nature of the failure is indicated in Fig. X—6 (b), and is caused by tensile forces acting obliquely to the grain. This commonly occurs in members containing spiral, diagonal or other forms of cross-grain on the convex side. If the inclination of the opening with reference to the edge of the mbmer is more than the permissible slope of grain in the beam under investigation, the data should be rejected and not used for further computations.

(iii) *Splintering tension.*—This type of failure is common in tough woods and fibrous materials. The failure appears like a ragged or splintery break on the tension. Surface of the beam as shown in Fig. X—6 (c).

(iv) *Brittle tension.*—Sometimes also known as brash failure, this occurs as a clean break extending entirely across the cross-section throughout the beam as shown in Fig. X—6) d). It is characteristic of brittle wood in which the material may give way suddenly without warning. Mechanically, this signifies that the maximum load is just above the load at proportional limit. Brashness is evidently associated with variations in the anatomy of wood like low density, thin-walled fibres, etc., but it may also be caused by the presence of incipient decay, inherently localised stresses, or exposure to weathering and high temperatures, etc.

(v) *Compression failures.*—This is a type indicated by Fig. X—6 (e), and is generally conspicuous in green material. The failure may start at different places from the neutral plane, but usually begins at the top side (concave side) immediately after the proportional limit is reached and extends downwards towards the neutral plane. Sometimes it may even cross the central plane before complete failure occurs, or may sometimes appear to run obliquely thus giving an indication that some type of diagonal shesr has taken place.

(vi) *Horizontal shear failure.*—This is indicated in Fig. X—6 (f) and represents a relative sliding between the upper and lower portions of the beam. It is fairly common when the ratio of height of the beam to its span is relatively large, and this is the reason why it is not common in the standard-size specimens. If, however, occurs in some types of specimens, the data should be rejected for further computations.

Failure under longitudinal compressive forces

Fig. X—7 indicates the typical failures that occur in members under longitudinal compressive forces. They reveal considerable variation in occurrence and development. They appear as localised wrinkles extending across the fibres with fairly pronounced ridges. Sometimes they may not be clearly

visible but all compression failures are associated with concentrated stresses in different zones and planes. The failures of timbers under compression parallel to grain are classified as follows :

(i) *Crushing*.—The type of failure occurs in the compression member of test specimens at portions that are relatively wet. When such a failure occurs at the extreme ends of the piece, it is called 'brooming; 'end crushing,' or 'end rolling' when it occurs in cetral region it is called simply 'crushing'. In all cases, the plane of rupture is approximately horizontal and the results are considered satisfactory when the failures occur in the central region with the face perpendicular to the longer edges of the specimens [Fig. X—7(a)]. Brooming [Fig.X—7(f)] may also occur when the ends of the specimen are not properly cut, and as such the data should be carefully examined before proceeding further when such types of failures occur.

(ii) *Wedge split*.—As shown in Fig. X—7(b), this is a typical shearing failure, accompanied by splitting when the member is mainly under compression parallel to grain. Such failures are due to internal deviations in grain.

(iii) *Splitting*.—A typical failure of this kind shown in Fig. X—7(d). This is characterised by tearing of the fibres along a vertical plane and generally occurs in dry materials.

(iv) *Shearing*.—This type of failure is shown in Fig. X—7 (c). Shearing is a term used commonly when the plane of rupture makes an angle with the axis of the specimen on its tangential face but is fairly horizontal on its radial face. This is one of the most commonly encountered failures and various explanations have been advanced for its occurrence, such as: (a) spiral arrangement of the rays as viewed on tangential section and spirals acting as lines of least resistance; (b) pronounced structural differences between early wood and late wood; (c) stiffening effect of the rays which increases the resistance to buckling in the direction of their length (radially), thus causing the inclination of the failure on the tangential face. None of these seems to be universally true and further detailed investigations are required.

(v) *Compression and shearing parallel to grain*.—This is a form that typically occurs in cross-grain material as shown in Fig. X—7 (e). If the results obtained on specimens showing such a failure are not satisfactory, they are discarded for further computations.

Failures under other stresses

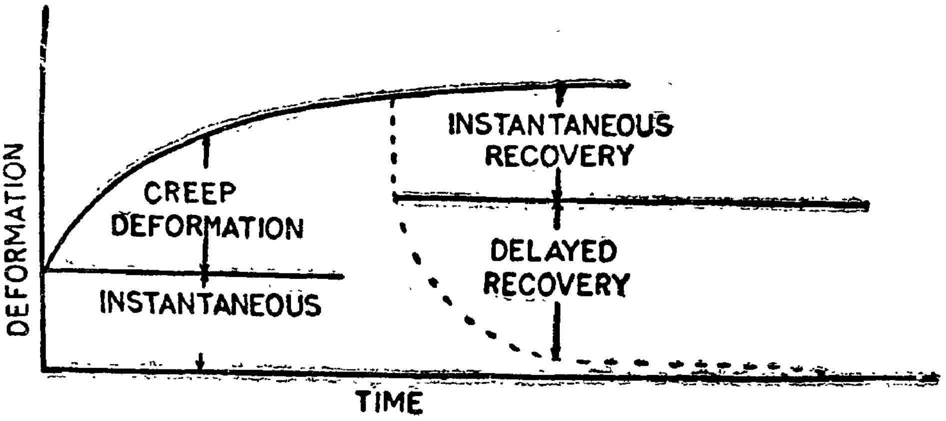
Failures under other types of stresses are equally important as those indicated above, and would provide useful information for the use of the right type of species for specific purposes. The subject of study is still in its infancy and need not be dealt with in detail here.

Elasto-Plastic Behaviour of Wood

In addition to normal "elastic behaviour" (i.e., the linear stress-strain relationship with the strain returning instantaneously to zero on the removal of stress), wood also exhibits, under certain conditions, "plastic behaviour", that is it is not only different from the two conditions indicated above but, under a constant stress, the strain goes on increasing with time until eighter the material breaks or a maximum strain is reached. Such a behaviour in wood is know as "elasto-plastic behaviour". Its study is of very recent origin, still involved in many exploratory investigations. The reverse phenomenon, namely, the variation of stress under a constant strain is also observed in wood. The former is known as "creep" and the latter as "stress-relaxation", sometimes referred to merely as "relaxation". When wood is subjected to continuous fluctuations of stresses and consequently of strains, it is said to be under " fatigue". On account of its elasto-plasticity, the behaviour of wood under fatigue is also different from that of other materials.

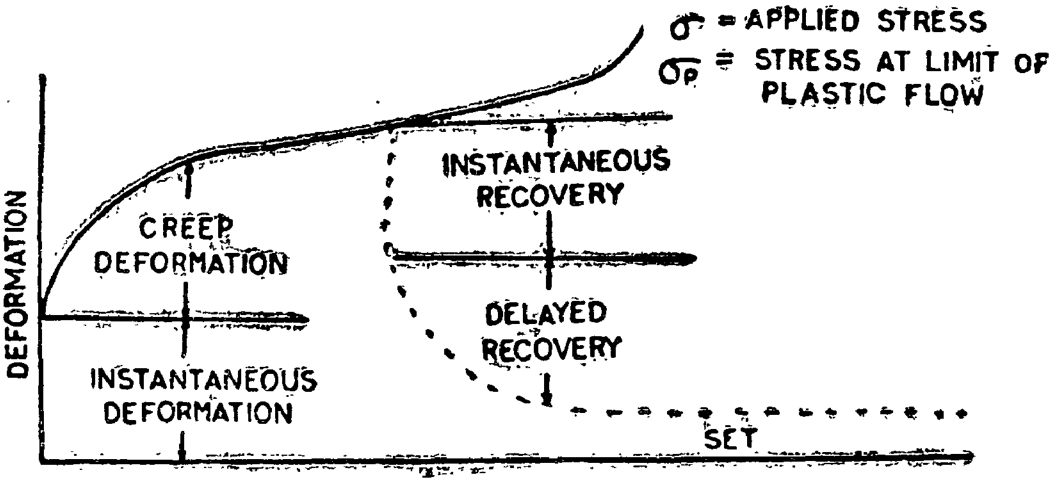
In the studies of creep, it has been observed that there are two distinct regions of stresses which have an influence on deformation of wood. The boundary between these two regions is known as "limit of plastic flow", say σ_p. Under stresses below σ_p, the rate of deformation under constant load gradually decreases to zero in course of time, and deformation itself ends to become a constant value after some time [see Fig. X—8 (a)]. On the release of the stress, the deformation is instantaneously reduced to some quantity but subsequently recovers completely, although only gradually over a fairly long period. However, if the initially applied stress is greater than σ_p, the rate of deformation diminishes at first, may remain constant for sometime, and finally increases till failure occurs [see Fig. X—8 (b)]. If the stress

is removed before such a failure occurs, deformation does not fully recover itself and a permanent set remains. In the various studies on creep, moisture content, temperature and the stress applied have been found to influence the creep behaviour of wood. Different species have shown different forms of creep behaviour and different limits of plastic flow under the same conditions.



TIME

Fig. X—8 (a); For $\sigma < \sigma_p$



TIME

Fig. X—8 (b). For $\sigma > \sigma_p$
Typical curves for timber.

Under continuous cycles of varying stresses, either from zero to the maximum value or from a negative value to a positive value, wood is found to fail completely after a number of cycles, depending upon the maximum stress of the cycle. The lowest limit of stress below which the material can withstand a very large number of continuous reversals of stresses, without any mechanical deterioration, is known as "fatigue limit". In many of the species, this limit works out to about 30 per cent of the normal breaking stress as determined under static tests. Below this limit, serveral species are known to withstand 15 to 125 million continuous vibrational reversals. A typical curve between the maximum stress of cycle and the number of million cycles required by the material to fail is given in Fig. X-9 (a). Unlike

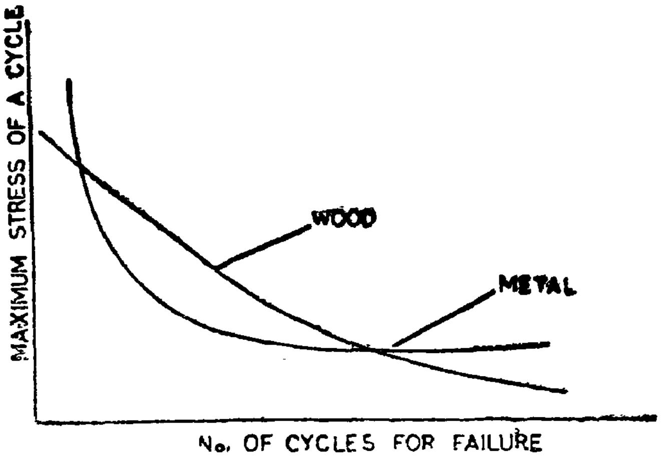


Fig. X—9 (a). Fatigue curve.

with many other materials, it is interesting to note that the inherent strength in a given piece of timber generally decreases with the increase in cycles of a given stress system, at a lower rate in the earlier stage and at a higher rate in the later stage as shown in Fig. X—9 (b). Other factors which are known to influence the fatigue behaviour are moisture content, temperature, rate of reversals, specific gravity and nature of stresses.

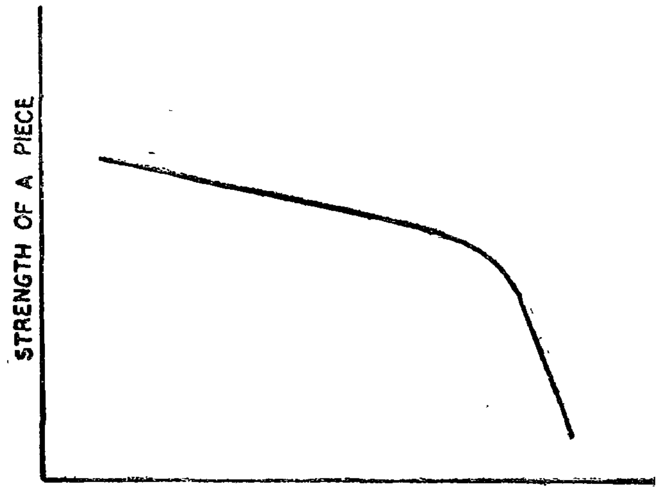


Fig. X—9 (b). Fatigue curve.

Further investigations in the above fields are being pursued in various laboratories of the world. Tentative results so far obtained in India are generally in accordance with the work done in other countries. Sekhar (1966) has proposed a generalized theory for elasto-plasticity of timber, taking also into consideration the orthotropic nature of wood. Some investigations have revealed that under dynamic conditions the anisotropy in wood may become insignificant for wood of very low specific gravity, i.e., below about 0.3.

BIBLIOGRAPHY

1.	Chaturvedi, M. D.	1955	Andaman timbers for Railway Sleepers; *Indian Railway Tech. Bull.*, Vol. XII, No. 119.
2.	Everett, W. H.	1906	Memorandum on Mechanical Tests of some Indian Timbers; *Forest Bull.* No. 6, Calcutta.
3.	Hartig, R.	1901	*Holzuntersuchunger Altes und Neues*, Berlin.
4.	James, W. H.	1916	The Strength and Elastic Properties of some South Indian and other Timbers; Professional paper No. 8, College of Engg.; Madras Govt. Press, Madras.
5.	Kann, J. H. C.	1923	Mechanical Tests of some Mysore Timbers; *Jr. Ind. Inst. Sci.* 5, Part XIV.
6.	Limaye, V. D. & Seaman, L. N.	1933	Third Interim Report on Proj. 1, *Indian Forest Records*, Vol. XVIII-Pt. X.
7.	Limaye, V. D.	1942	Interim Report on the relation between Rate of Growth and strength of Natural and Plantation Teak; *Indian Forest Bulletin* (New Series), Utilisation, No. 113.
8.	Limaye, V. D.	1944	Suitability and Selection of Timbers for different uses, Pt. I and II; *Indian Forest Records* (New Series), Utilisation Vol. 3, No. 5.
9.	Limaye, V. D.	1954	Grouping of Indian timbers and their uses and Suitability; *Indian Forest Records* (New Series), Timber Mechanics, Vol. 1, No. 2.
10.	Markwardt, L. J.	1930	Comparative Strength Properties of Woods growth in United States, U.S. Dept. of Agri; *Tech. Bull.* No. 158, Washington.
11.	Nair, K. R. & Mukerji, H. K.	1957/60	A Statistical Study of the variability of Physical and Mechanical Properties of *Tectona grandis* (teak) grown at different localities of India and Burma and the Effects of the Variability on the choice of the Sampling Plan; *Indian Forest Records* (Statistical), Vol. 1, No. 1.

12. Paul, H. 1930 The Application of Silviculture in controlling the Specific Gravity of Wood; U.S. Dept. Agri.; *Tech. Bull.* No. 168, Washington.

13. Pearson, R. S. 1911 Note on the Relative Strength of Natural and Plantation Grown Teak Burma; *Forest Bull.* No. 3.

14. Pearson, R. S. 1913 A Further Note on the Relative Strength of Natural and Plantation Grown Tea in Burma; *Forest Bull.* No. 14.

15. Seaman, L. N. 1924 Interim Report on work under Proj. 1 and Proj. 0; *Indian Forest Records*, Vol. X, Pt. VII.

16. Seaman, L. N. & Ranganathan, C. R. 1926 Second Repo r ton work under Proj. 1; *Indian Forest Records*, Vol. XII, Pt. III.

17. Seaman, L. N. 1933 Interim Report on work under Proj. 2, Strength Tests of Timbers in Structural size; *Indian Forest Records*, Vol. XVII, Pt. VII.

18. Sekhar, A. C. & Sharma, R. S. 1955/56 Variation of Izod values with Temperature in Timber; *Indian Forester* Vol. 82, No. 1 and *Indian Forest Leaflet* No. 141.

19. Sekhar, A. C, & Negi, D. D. 1955/57 Studies of Izod values of some Indian Timbers; *Indian Forest Bull.* No. 201.

20. Sekhar, A. C. & *et al* 1955/65 Physical and Mechanical Properties of Woods tested at F.R.I., Report Nos. IV, IX *Indian Forest Records*, Vol. 1, Nos. 3, 6, 7, 8, 9, & 10.

21. Sekhar, A. C. & Rana, R. S. 1956 Nail and Screw Holding Power of Indian Timbers, Pt. I; *Indian Forest Records* (New Series), Timber Mechanics, Vol. 1, No. 5.

22. Sekhar, A. C. 1956 Evaluating Suitability of Indian Timbers for use as Railway Sleepers; *Indian Railway Tech. Bull.*, Vol. XIII, No. 122.

23. Sekhar, A. C. & Rawat, B. S. 1958 Influence of size, Shape and Notches in Test Specimens in Timber; *Holz-als-Ron-und Werkstoff* Vol. 16, No. 3.

24. Sekhar, A. C. & Rawat, B. S. 1959 Studies on Effect of Specific Gravity on Strength Considerations of Indian Timbers; *Jr. Inst. of Engineers* (India), Vol. XXXIX No. 8, Pt. 1.

25. Sekhar, A. C. & Negi, G. S. 1959 A Note on Coefficients of Variation for Mechanical properties of Indian Woods; *Jr. N. B. O.*, Vol. IV, No. 2.

26. Sekhar, A. C., Bhartari, R. K. & Rawat, M. S. 1960 Comparative studies on Natural and Plantation Teak; *Indian Forest Bull.* No. 227 (New Series), Timber Mechanics.

27. Sekhar, A. C. & Bhatia, D. N. 1960 Note on Evaluation of Splitting Coefficients of Timbers; *Indian Forest Bull.* No. 222 (New Series), Timber Mechanics.

28. Sekhar, A. C. & Negi, G. S. 1961 Studies on Variation of strength Properties of Indian Timbers; *Vishwakarma*, Vol. 2, No. 7.

29. Sekhar, A. C. 1962 A Note on some recent Trends in Teak Utilization in India; *Jr. Soc. of Ind. Foresters*, Vol. II, No. 2.

30. Sekhar, A. C., Rawat, B. S. & Bhartari, R. K. 1962 Strength of Bamboo (*Bambusa nutans*); *Indian Forester*, Vol. 88, No. 1.

31. Sekhar, A. C. & Sharma, R. R. 1964 A Note on Mechanical Properties of Twisted Chir from U.P. (Almora Division); *Jr. Soc. Ind. Foresters*, Vol. IX, Nos. 2 & 3.

32. Sekhar, A. C. & Gupta, V. K. 1965 Influence of Temperature on Mechanical Behaviour of some Indian Timbers; *Materialprufung* 7, No. 3.

33. Sekhar, A. C. & Rajput, S. S. 1965 Some observations on the effect of size and shape of test specimen and direction of load on some Mechanical Properties of Wood; *Materialprufung* 7, No. 9.

34. Sekhar, A. C. 1966 Dynamic stresses in Timber; *Holz-als-Roh-und-werk-stoff*, Vol. 2[illegible], No. 11.

35. Sekhar, A. C. & Negi, G. S. 1966 Variation of some Mechanical Properties along the Length of Teak Trees; *Indian Forest Bull.* No. 251 (New Series), Timber Mechanics.

36. Sekhar, A. C. & Sharma, R. S. 1966 Comparative Studies on Mechanical Properties of Natural and Plantation Grown *Terminalia myriocarpa* (Hollock); *Indian Forest Bull.* No. 249 (New Series), Timber Mechanics.

CHAPTER XI

CHEMISTRY OF WOOD AND WOOD COMPONENTS

ntroduction

Wood, as a product of biological development, is a complex substance both anatomically and chemically. It is a heterogeneous substance, differing markedly between trees of different species, to some extent between individuals of the same species, and not unoften even from part to part within the same tree, e.g., trunk and branch, sapwood and heartwood, and springwood and summerwood.

While inert in many respects, wood is readily oxidized (burnt), dissolved, or converted into some other products under suitable conditions or treatments. The chemical utilization of wood will come up for study under several headings such as pulping, extraction of various products (essential oils, tannins, dyes, etc.), hydrolysis (i.e., conversion of carbohydrates into sugars), destructive distillation, and chemical treatments designed to improve the properties of wood. A knowledge of the chemistry of wood and its components is therefore an essential preliminary to the understanding of the principles and techniques in the different fields of chemical utilization.

In general, wood contains two different types of chemical components : (1) those that are insoluble in neutral solvents and/or non-volatile with steam, and (2) those that are extractable by such solvents and/or isolable by steam. The substances belonging to the first category are designated as "wood substances" or "cell-wall substances" while those of the second category are called "extractives" or "extraneous substances".

Cell-wall substances

The cell-wall substances, as the name itself indicates, are the components of the cell wall. They include cellulose, other polysaccharides associated with it, and lignin. The total carbohydrate fraction of the cell wall is sometimes referred to as holo-celluloses. In addition to the above components, the cell wall invariably retains small amounts of mineral matter. Also, there are some acetyl, formyl and methoxyl groups attached to the skeletal substances.

Cellulose.—Forming the skeleton of the cell walls, cellulose is the most widely occurring organic substance known in nature, and constitutes 40 to 50 per cent of wood. It is characterised by its inertness to the action of dilute acids and alkalis. Cellulose is not to be viewed as a chemically well-defined and homogeneous compound but only as a mixture of homologous polymers.

Other polysaccharides.—The other polysaccharides of the cell walls vary from about 10 to 25 per cent. They are mostly hemi-celluloses and to some extent mucilages. Chemically these two classes of compounds are very closely related; both of them are neutral as well as acid polysaccharides. They differ in their properties mainly in two respects; (1) the aqueous solutions of mucilages are slimy and mucilaginous, while those of hemi-celluloses are not; and (2) mucilages do not undergo complete hydrolysis with dilute mineral acids easily and readily, while hemicelluloses do. Wood mucilages do not seem to have been isolated and studied to any extent.

Hemi-celluloses are partly skeletal and incrusting and partly reserve materials; they occur not only as cell-wall constituents and their incrustations but also within the cell. They are, in general, extractable with dilute alkalis and not with water, and are readily hydrolysable to the constituent sugars and sugar acids by boiling with dilute mineral acids. They appear to be in some sort of chemical combination with the other cell-wall components, namely, cellulose and lignin, because, while they are not extractable with water from the original material, they become soluble in the same solvent when once they are isolated. Those hemicelluloses which are not detached from cellulose, during what is known as the Cross and Bevan treatment (with alkali and chlorine) of the wood, are called cellulosans. These are usually neutral polysaccharides like xylans, mannans and glucans, and are skeletal substances.

Those that go into solution during the Cross and Bevan treatment are neutral as well as acidic polysaccharides (polyuronides). These arise from the reserve carbohydrates of the cell sap and the incrustations of the cell wall. However, there is no sharp boundary between these different groups.

Pectins also occur in wood in small quantities (1 to 2 per cent), but it is not yet known whether they are present as cell-wall components, though they have been extracted from the holo-cellulose fractions in several cases. However, it has not yet been possible to extract them from wood by means of neutral solvents, and hence technically they cannot be classified as extractives. It is worthwhile to note that non-lignified tissues contain relatively large amounts of pectins and no lignin at all and, oldly enough, no carbohydrates also other than "cellulose". The middle lamella is said to contain pectins, probably as calcium pectinate in the early stages of cell multiplication, and very likely they may be undergoing chemical changes during the subsequent stages of the cell development.

Lignin.—Lignin may be defined as that incrusting material of the plant tissues that is built up mainly, if not entirely, of phenyl propane units and is unhydrolysable by acids, easily oxidisable, and soluble in hot alkali and bisulphite; it condenses readily with phenols and thio-compounds and gives a series of specified colour reactions. It is present in wood to the extent of 20 to 35 per cent. As the cell wall matures, the primary wall together with the intercellular substance acquires large deposits of lignin, so that the middle lamella and the two primary walls become one in many respects to form what is called the compound middle lamella. Hence most of the lignin, say up to about 70 per cent, is found in the compound middle lamella. It thus forms an incrustation, encasing the primary walls and the middle lamella. In the secondary wall, lignin on the one hand and cellulose and the other polysaccharides on the other form interpenetrating systems, giving the appearance of concentric rings. Only a small portion of lignin appears to be present in a free state while the rest is partly or entirely combined with other wood constituents, namely, cellulose, hemi-celluloses or even relatively simple sugars. It is not to be viewed as a definite chemical entity but as a mixture of high-molecular, amorphous compounds. that are chemically alike in the same sense as different kinds of cellulose, hemi-celluloses and starch are.

Extraneous substances

The extraneous substances, to the best of our knowledge, are not a part of the cell wall; they are found in the lumina of the cells. Most of them are removed either by steam-distillation or by extraction with neutral solvents like benzene, ether, alcohol, acetone, gasoline and water. However, there are a few exceptions. For instance, the native lignin which is a cell-wall component is extractable by neutral solvents like ethanol or dioxane, while the insoluble crystals of various calcium salts, though belonging to the class of extraneous substances, cannot be extracted by neutral solvents. While the cell-wall components are primarily cellulose, hemi-celluloses and lignin, the extraneous substances are varied in nature and in number. Some tropical woods like quebracho (*Schinopsis lorentzi*) contain as high as 40 per cent of the extractives, while others like sugar maple (*Acer saccharum*) or yellow birch (*Betula* spp., mainly *B. lenta*) may contain as low as 2 per cent.

The extraneous substances often serve to characterise the wood. Thus durability, colour, odour, taste, inflammability, toxicity, density, etc., are often correlated with the presence or absence of these extraneous substances. For instance, the presence of certain phenols and other toxic substances, though in very small amounts prevents the decay of certain woods. In many cases the trees are valued more for their extractives which are of great economic value (e.g., resin acids, essential oils, tannins, alkaloids, etc.), the extractives frequently determining the use to which a particular wood can be put. These extractives are sometimes so very characteristic that they offer a means of differentiation and identification of a species.

In certain trees, however, the presence of these extractives is not altogether a happy feature because they interfere with their industrial utilisation. For instance, the presence of pinosylvin, a dihydric alcohol, prevents the successful sulphite-pulping of several pine species, though it prevents the decay of the old pine stumps. Another instance is the corrosion caused to the metal equipment by thujaplicins found in western red cedar (*Thuja plicata*) and by free formic and acetic acids present in *guijo* (*Shorea guiso*), a Philippine wood. Similarly, the presence of starch in certain woods is responsible for the insect and fungal attack they are susceptible to. In a like manner the alkaloid chloroxylonine present in satinwood (*Chloroxylon swietenia*) may cause dermatitis to the workers.

The nature of the extractives, as already stated, varies markedly. There are inorganic as well as organic substances in them.

Inorganic extractives.—The inorganic substances are either purely inorganic salts, including free silica, or salts of organic acids, and these form the ash on burning. The ash content and composition vary with the place where the wood is grown, the growing conditions and the season of the year. The metallic radicles are principally calcium, potassium and magnesium; aluminium, iron, manganese and sodium are also frequently met with. But sometimes some of the latter metals predominate, for example, the ash of *Abies pectinata* contains nearly 40 per cent of potash and 28 per cent of manganese oxide, while the ash of *Orites excelsa* contains as high as 75 per cent of alumina. Furthermore, there are cases where barium, titanium, lead, zinc, copper, tin, cobalt, nickel, thallium, chromium, silver and even gold have been detected in very samll amounts. Some of these trace elements are said to play a vital role in the plant metabolism. As regards the acid radicles, the inorganic ones usually present are carbonate, sulphate, silicate and phosphate, although the chloride radicle also occurs in several cases.

Organic extractives.—As extractives, organic acids comprise a large number, chiefly aliphatic, starting from the most elementary formic and acetic acids and going up to the higher fatty acids. An interesting volatile acid is the 7-membered thujic acid obtained from the wood of *Thuja plicata.* The so-called "sugar sand", which separates from maple syrup, is the insoluble calcium malate. However, it is not to be understood that all these and other acids are found only as salts. Some of them may be either free or in combination with other organic substances. In fact, oils and fats are the glycerides of the higher and middle fatty acids, while the vegetable waxes are the esters of the higher monobasic carboxylic acids with the higher monohydric (seldom dihydric) alcohols.

As for the other organic extractives, the following groups may be found; essential oils, fixed oils, resin acids, sterols, tannins, dyes, cyclitols, polysaccharides, alkaloids, small amounts of proteins (arising from dried protoplasm), etc.

The more important among the organic extractives are briefly dealt with below :

(1) *Essential oils.*—Essential oils are present in most of the woods to some extent or other, usually below 1 per cent, but there are some woods like mlanje cedar (*Widdringtonia whytei*) and several species of *Araucaria* which contain as much as 12 per cent and above of oil. Indian sandalwood (*Santalum album*) contains as high as 8 per cent of an essential oil in some samples. The oils are usually obtained from the heartwood, either by steam-distillation or solvent extraction or by destructive distillation, and are known to the trade either as wood turpentines or as wood oils. The natural resistance of certain woods to decay is attributed in part to the presence of these volatile constituents. It may be noted that the quality of the oil varies considerably from species to species and also from one part of the same tree to another, say the flower and the bole. Some of the commercially important wood oils are those obtained from pines (*Pinus* spp.), cedars (*Cedrus* spp.), camphorwood (*Cinnamomum camphora*), sassafras (*Sassafras officinale*), hinoki wood (*Chamaecyperis obtusa*), linaloe wood (*Bursera delpechianum*), rosewood (*Dalbergia latifolia*), sandalwood and agarwood (*Aquilaria agallocha*).

Chemically, essential oils are mixtures of various types of compounds : hydrocarbons, acids, phenols, alcohols, esters, ethers, aldehydes, ketones, oxides, lactones, etc.

(2) *Wood resins.*—Resins occur widely distributed in the plant kingdom. They are found not only in the intercellular passages (resin channels) but also in the cell walls and the interior of the cells. They are composed of resin acids and fatty acids, either free or in combination with terpenes and other alcohols, along with unsaponifiable matter consisting of sterols, alcohols, waxes and resenes. The resins are important because they are the source of raw materials for the extensive 'naval stores' industries. The amount of resin varies from 0.8 to 25 per cent in softwoods and from 0.7 to 3 per cent in hardwoods. Further, the yield as well as the composition of the resin varies from one part to another in the same tree.

Resin may be obtained from (1) the living trees as oleo-resin (from sapwood), (2) from aged stumps as heartwood resin, and (3) from felled trees as tall oil. The oleo-resins usually contain about 66 per cent resin acids and 25 per cent of turpentine, the rest being mostly non-volatile neutral material. The non-volatile portion of the oleo-resin is known as 'gum rosin' which finds extensive use in the paper, soap, paint and varnish industries. It is also used in the manufacture of various chemicals,

pharmaceuticals and synthetic resins. The esters of rosin with glycerine and pentaerythritol are used as plasticizers and softeners in nitro-cellulose lacquers and thermoplastics. By destructive distillation rosin gives rise to what is called rosin oil.

'Wood rosin' is the product obtained from aged stumps by extraction with gasoline or benzene, after distilling off the wood turpentine by steam-distillation. Alternatively, both the oil and the rosin are first extracted with solvents and then separated by stem-distillation. The resin acids of this rosin are essentially the same as those of gum rosin; the neutral fraction, however, differs.

'Tall oil' is primarily a mixture of free fatty and resin acids, in almost equal amounts, and 10 per cent of neutral material. The resin acids have essentially the same composition as that of wood and gum rosins, while the fatty acids comprise chefly oleic and linoleic acids. The neutral material considerably differs, and contains a good proportion of sitosterol, which is isolated in some cases on a commercial scale. Tall oil is produced during the soda and sulphate pulping process of the paper industry. On concentrating and cooling the alkaline waste black liquor, the sodium salts separate out. They are collected, washed and acidified when tall oil is generated. The oil is used extensively in metal polishes, horticultural sprays, paper sizing, textile lubricants, soaps, etc.

(3) *Dyes and tans.*—Apart from the bark, roots, leaves, flowers, and other parts of the plants, wood itself contains many tanning and colouring matters. Some of them are present in sufficiently large amounts as to be of commercial importance, for example, quebracho wood and chestnut wood (*Castanea dentata*) which yield commercial tannins. The wood of khair (*Acacia catechu*) is largely worked in India for the production of *katha* (catechin) and cutch. *Katha* is in great demand in India for use in *pan.* The main use of vegetable tannins is in the conversion of hides and skins into leather. Further, large amounts are used in drilling oil wells to control the viscosity and water loss of drilling fluids and in water treatment. They are also used to some extent as antioxidants in edible fats, in the floatation of certain ores, for the removal of mercaptans from gasoline, etc.

The tannins aid in protecting the tree from insect and fungal attack. In this connection it may be interesting to note that the redwood (*Sequoia sempervirens*) forests are almost free of bird life on account of the absence of insects in those forests.

The colouring matters in woods may comprise unsaturated hydrocarbons, ketones, quinones, flavones and related materials, and substances of uncertain structure. At one time some of the colouring matters were used as commercial dye-stuffs, e.g., logwood (*Haematoxylon compechianum*), old fustic (*Chlorophora tinctoria*), khair, Brazilwood (*Caesalpinia* sp.), camwood (a variety of *Baphia nitida*), young fustic (*Rhus cotinus*), red sanders (*Pterocarpus santalinus*) and barwood (*Baphia nitida*), and in spite of the competition from synthetic dye-stuffs, some of them are still in demand, for example, logwood. Besides their limited use as commercial dye-stuffs, the nature of the colouring matter determines the commercial value for a particular species. For instance, mahogany (*Swietenia mahagoni*) and ebony (*Diospyros* spp.) are in great demand for furniture because of their attractive natural colour.

(4) *Carbohydrate components.*—Although the principal polysaccharides of wood are found in the cell wall, the cell fluid also contains many soluble carbohydrates: simple sugars, glycosides and polysaccharides. Amongst the latter, starch ranks foremost and is the chief reserve carbohydrate. It varies from 0.5 to 5 per cent. A serious disadvantage of the presence of large amounts of starch is that, when the trees are cut, the wood becomes susceptible to insect attack. In order to avoid this danger, it is essential to see that the starch content is brought down to below the danger level. This can be done by allowing the cut logs to dry at the atmospheric temperature, without removing the bark in order to prevent rapid drying. Under these conditions the storage cells do not die all at once but try to keep themselves alive, gradually exhausting the starch till it is finished. If, however, the storage cells are rapidly killed by kilning, the reserve starch remains in tact, making the wood vulnerable.

(5) *Cyclitols.*—Belonging to the group of cyclic polyhydric alcohols, the cyclitols are an interesting group of compounds. They have the same empirical formulae and molecular weights as hexoses and methyl pentoses, and are also sweet like the sugars, but they neither contain any carbonyl group nor do they ferment. The origin and function of these cyclitols are not definitely known. Of these compounds, the quercitols with five hydroxyl groups and inositols with six hydroxyl groups are important. A number of the methyl ethers of inositols occur in several woods.

(6) *Other extraneous substances.*—There are a few other extraneous substances which need not be mentioned in any detail because they are either too few (fatty oils) or too many (alkaloids). For instance, wood is not a suitable source for the isolation of fixed oils, and consequently these oils, as obtained from woods, have not been much studied. Even linden wood (*Tilia* spp.), which contains as much as 7 to 8 per cent of an oil on dry weight, does not compare favourably with other sources. Trees like *Tilia*, *Betula* and *Pinus sylvestris* which are rich in fatty oils are called 'fat trees', as opposed to 'starch trees' whose reserve nutrient is starch. The 'fat trees', according to one hypothesis, derive their energy from fats. In general, the 'fat trees' are of softwoods while the 'starch trees' are of hardwoods. Chemically, the wood fatty oils do not appear to differ from the seed oils.

On the other hand, several alkaloids have been isolated from different species of wood, but it is not possible to deal with them in a general chapter. In passing, it may be mentioned that the presence of the alkaloids in woods is both a boon and a curse. Some of the alkaloids are very valuable therapeutic compounds with high physiological activity. Apart from their utility to man to counteract ailments, they may offer protection to wood against insect attack. At the same time their presence renders the woods toxic, giving rise to hazards when they are exploited in industry. Several woods belonging to Anacardiaceae, Apocynaceae, Euphorbiaceae, Leguminosae, Loganiaceae, Rutaceae and Rubiaceae are toxic, and cause dermatitis on account of their alkaloidal content.

Most of the alkaloids are colurless bitter solids; however coniine and nicotine are volatile liquids, and berberine is a yellow solid. They are usually present in small amounts (less than 1 per cent), but there are cases like berberine which is present to the extent of 4.8 per cent in the wood of *Arcangelisia lemniscata*.

REFERENCES

1.	Hawley, L. F. & Wise, L.E.	1926	The Chemistry of Wood; The Chemical Catalog Co., Inc., New York.
2.	Hagglund, E.	1951	Chemistry of Wood; Academic Press Inc., Publishers, New York.
3.	Rao, P. S.	1951	A note on Hemi-cellulose; *Science and Culture*, Vol. 17 No. 2; Indian Science News Association, Calcutta.
4.	Wise, L. E. & Jahn, E. C.	1952	Wood Chemistry; Reinhold Publishing Corporation, New York.

CHAPTER XII

WOOD-WATER RELATIONSHIP

Wood, being hygroscopic subsance, contains varying quantities of water not only in the freshly felled raw condition but also in the air-dry condition in service. The affinity of wood for water has far-reaching consequences in the utilization of wood, as this affects its several important properties. Variation in the amount of water held by wood causes shrinkage or swelling, changes the various strength properties, electrical resistance, dielectric and thermal properties, the susceptibility of wood to fungal infestation and indirectly affects the adhesion of glues and finishes. Knowledge of wood-water relationship is, therefore, essential for efficient processing of wood.

Forms in which water is held in wood

In green wood, water is contained in the permanently existing voids of the microscopic cell cavities as well as in the finer sub-microscopic voids of the swollen cell wall, which are transient in nature and are created as a result of swelling.

The bulk of water contained in the cell cavities is free from the action of intiermole cular attraction of the cell walls and is only held by capillary forces. It is, therefore, termed as *free water.*

The water which is contained in the transient voids of the cell wall is more intmataly associated with the wood in its sub-microscopic structure. The attraction of wood for water arises from the presence of free hydroxyl (OH) groups in the chemical structure and arrangment of the cellulose molecules within the cell wall. The hydroxyl groups are negatively charged electrically and, since water is a polar liquid consisting of a negative hydroxyl (OH) fraction and a positive hydrogen (H) fraction, the free hydroxyl groups in cellulose attract and hold water by hydrogen bonding. The water held in the cell walls by such bonds is termed as ***adsorobed, hydroscopic*** or ***bound water.***

The cell walls are a mesh-work of strand-like sub-microscopic structural units, called micro-fibrils, which are in reality aggregates of long chain molecules of cellulase. The long chain molecules become alternately parallel and non-parallel in their orientation within the micro-fibril, giving rise to alternating crystalline and amorphous zones. The hydroxyl groups on the long chain molecules of cellulose in the interior of the crystalline zones are engaged in cohesive cross-bonding be ween adjecent cellulose chains, and are therefore not available for obsoring water. The major portion of the bound water is, therefore, taken up in the amorphous zones of the cell wall and only a small protion on the peripheral surfaces of the crystalline zones. The water in these two zones is absorbed in polymolecular or monomolecular layers. The cell wall swells in order to accommodate these layers of obsorbed water. A very small quantity of bound water is also held by capillary condensation in the pre-existing voids in the cell walls, which are present even in the oven-dry condition.

Moisture content of wood

The amount of water contained in wood is usually expressed as a percentage of its oven-dry weight and is termed as *moisture content.* The oven-dry weight is the standard condition of dryness of wood and is the virtually constant weight attained by a piece when it is oven-dried at 100° to 105°C. It represents the condition when practically all the water has been removed from wood, except minute traces which cannot be removed under the oven drying conditions without prolonging the drying to an extent where some thermal degradation of the wood also sets in.

The loss or gain of moisture by wood is also generally expressed with reference to its oven-dry weight, except in measurement of dryage of fuel wood where it is expressed with refernce to the initial wet weight for the sake of convenience in transactions. The method of expressing the quantity of moisture on the basis of the oven-dry weight of wood is preferred for most purposes, as the values thus calculated are more directly relevant to the basic properties of wood.

Maximum mosture content of wood.—The moisture content of wood is at its maximnm when the cell walls are completely saturated and the cell cavities are filled with water. The amount of water which wood can contain in this water logged condition limited by the total void space available in the swollen wood, and is therefore contingent on the volume of wood substance present relative to the external swollen volume of the gross wood. The maximum moisture content is given by the formula :

$$M=\left(\frac{1}{S_g} - \frac{1}{1.46}\right) \times 100$$

where,

M = Maximum moisture content (per cent),

S_g= Sp. gr. of wood on the oven-dry weight/swollen volume basis ; and

1.46 = Sp. gr. of oven-dry wood subtance determined by helium displacement.

The maximum moisture content is of the order of 64% for heavy axlewood (sp. gr.=.757), 112% for the moderately heavy teak (sp. gr.= .554), and 235% for a light packing case hard wood usch as semul (sp. gr. = .329).

Moisture content of wood in the living tree.—A completely waterlogged condition of wood rarely obtains in nature, and wood, as it comes from the living trees, generally contains varying quantities of air in the form of bubbles in the cell cavities. The moisture content of wood in the living trees, even of the same species, is highly variable. It appears to be variously affected by a number of factors, such as position in the stem (longitudinal or transverse, sapwood or heartwood), sp. gr. variation, locality factors and seasons of the year.

In addition to the localized flactuations of moisture content which occur in the wood of a tree, the mositure content also varies with the species of wood. Variation between species may range from 30 to 200%. Moisture contents of the order of 80% have been observed in moderately heavy woods like teak and sissoo, as a result of laboratory tests on various properties of green wood. Light hardwoods, such as semul, have shown moisture contents as high as 150%, while heavy timbers like axlewood have shown moisture contents of about 50%.

Lowest moisture content at which wood sinks in water.—When the sp. gr. of wood, based on wet weight and swollen volume, exceeds unity, i.e., the sp. gr. of water, the wood cannot float. The minimum moisture content M at which wood sinks in water can be found from the formula :

$$M = \frac{100\ (1-S_g)}{S_g}$$

where, S_g=Sp. gr. based on oven-dry weight and swollen valume. These calculations are of interest in connection with the water transportation of wood.

Moisture content of wood in relation to relative humidity (sorption curves).—The water contained in wood exerts a vapour pressure of its own, which is determined by the maximum size of capillaries filled with water at any time If the water vapour pressure in the ambient space is lower than the vapor pressure within the wood, desorption takes place. The largest-sized capillaries which are full of water at the time empty first. The vapour pressure within the wood falls as water is successively contained in smaller and smaller sized capillaries. A stage is eventually reached when the vapour pressure within the wood equals the vapour pressure in the ambient space, and further desorption ceases. The amount of moisture which remains in the wood at this stage is in equilibrium with the water vapour pressure in the ambient space, and is termed as *Equilibrium Moisture Content* (E. M. C.).

The equilibrium moisture content of wood varies with the ambient relative humidity, to a lesser degree with the temperature and the direction of sorption (desorption or adsorption) in which the moisture exchange takes place. Figs. XII—1 and XII—2 illustrate the equilibrium moisture content—relative humidity relation-ship for wood and the effect of vaiiovs factors on the same.

In the desorption curves the initial green moisture content of the wood has not been indicated. In this condition the cell walls are completely saturated with water and the cell cavities contain varying quantities of miosture, It is believed that the whole of the free water from the cell cavities of green wood

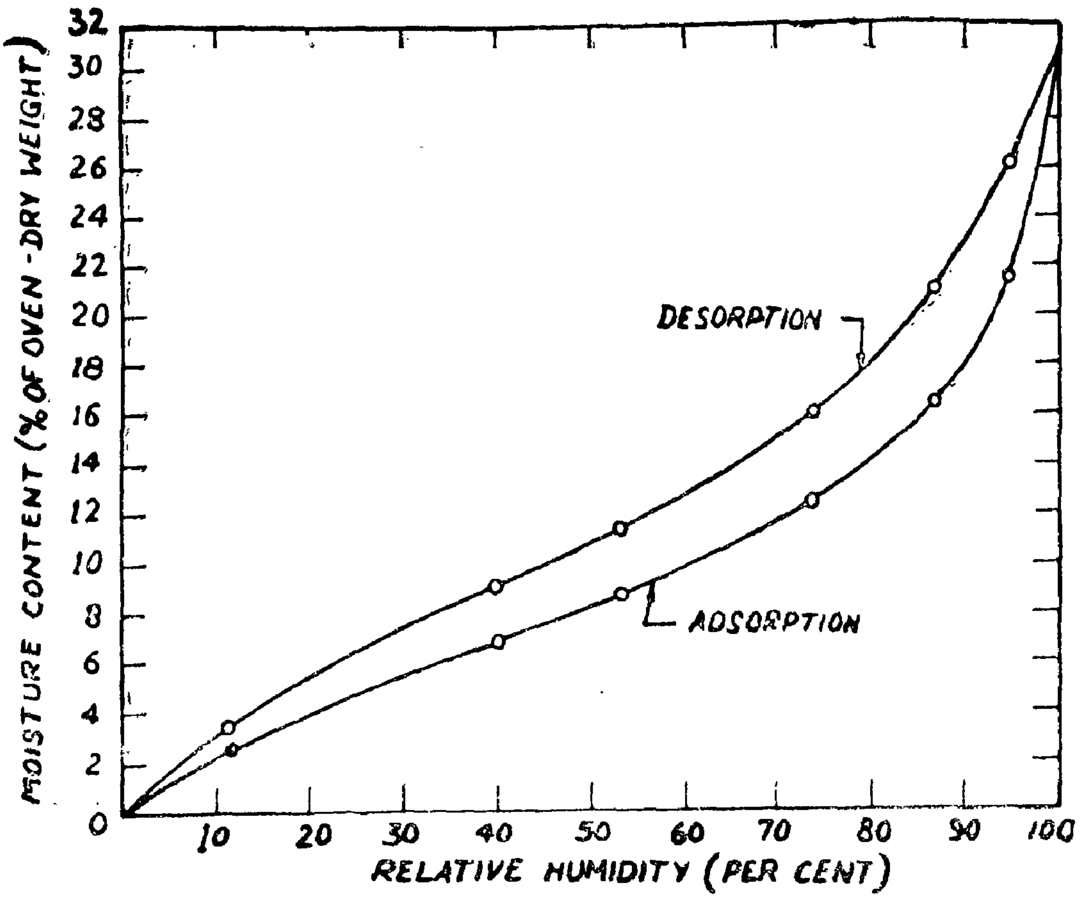


Fig. XII—1. Adsorption-desorption isotherms for water vapour by spruce at 25°C.

(Adapted from Stamm, A. J.)

can be removed if the wood is allowed to attain equilibrium with an ambient relative humidity of 99.5 per cent. Further reduction of relative humidity to 90 per cent removes bound water, which is held by capillary condensation in the limited volume of permanent voids in the cell wall. Still further reduction of relative humidity from 90 to 20 per cent removes all the polymolecularly held bound water from the cell wall. The tenaciously held monomolecular layer of adsorbed water is removed completely only when the wood is oven-dried.

Wood shows hysteresis in sorption, i.e., the moisture content attained by adsorption from the dry condition is always less than the moisture content retained on desorption at a fixed relative humidily, except at the extremes (Fig. XII-1). The adsorption-desorption ratio is found to be approximately constant (0.82) for wood, at all relative humidities from 10 to 90 per cent.

An increase of temperature at which desorption takes place causes a decrease in the equilibrium moisture content at all relative humidities. The decrease is of the order of 0.1 per cent per degree centigrade increase in temperature at each relative humidity.

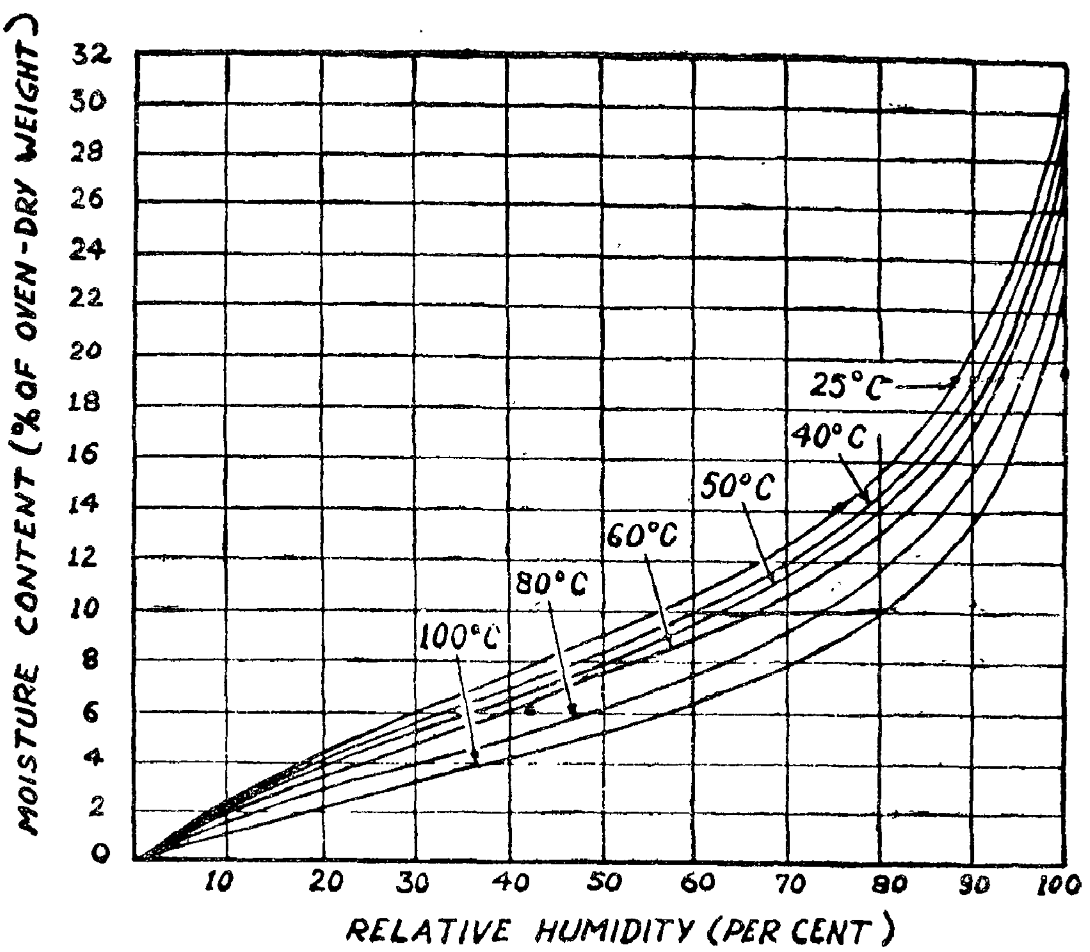


Fig. XII—2. Desorption isotherms for water vapour by Sitka spruce specimens at different temperatures.

(Adapted from Stamm, A. J.)

An appreciable permanent decrease in the hygroscopicity of wood can be achieved by heating wood in an inert atmosphere at high temperature of the order of 100°C and above, as also by chemical treatments such as acetylation. No appreciable differenecs in hygroscopicity were recorded between wood which was air-dried at atmosheric conditions and wood which was kiln-dried, employing medium temperature schedules and including steaming treatments at 60°C and 100% relative humidity, in a study carried out on six species of Indian timbers.

The effects of temperature and hysteresis on the equilibrium moicture content of wood are of importance in the proper understanding and operation of the kiln-drying process and conditioning treatments for timber. The relative hygroscopicity of idfferent woods is one of the criteria governing their relative suitability from the point of view retention of shape and size in service. The equilibrium moisture contents of some Indians species determined at 35°C and two different relative humidities (96% and 30%) are given in Table XII-1. The low equilibrium moisture content of certain woods like teak and padauk is attributed to their high extractive content.

TABLE XII-1

Equilibrium moisture content of 58 *Indian woods at* 96% *and* 30% *R. H. and* 35°C *temperature*

(From *Ind. For. Rec.*, Vol. 2 No. 10, Utilization)

Sl. No.	Species	Moisture content at 96% R. H. per cent	Moisture content at 30% R. H. per cent	Difference in moisture content (Col. 3-Col. 4) per cent
1	2	3	4	5
	Group A			
1	*Artocarpus hirsuta* (aini)	17.0	5.1	11.9
2	*Cedrus deodara* (deodar)	17.6	5.7	11.9
3	*Dalbergia latifolia* (rosewood)	16.1	4.3	11.8
4	*Gluta tavoyana* (gluta)	15.9	4.9	11.0
5	*Pterocarpus dalbergioides* (Andaman padauk)	14.0	4.0	10.0
6	*Pterocarpus marsupium* (bijasal)	17.5	5.0	12.5
7	*Tectona grandis* (teak)	16.0	4.3	11.7
	Group B			
8	*Albizia lebbeck* (kokko)	18.8	4.8	14.0
9	*Albizia procera* (white siris)	17.9	4.9	13.0
10	*Artocarpus chaplasha* (chaplash)	17.5	4.9	12.6
11	*Dalbergia sissoo* (sissoo)	17.2	4.6	12.6
12	*Duabanga grandiflora* syn. *D. sonneratioides* (lampati)	19.3	5.9	13.4
13	*Hardwickia binata* (anjan)	19.1	5.6	13.5
14	*Hopea parviflora* (hopea)	19.3	6.1	13.2
15	*Lagerstroemia lanceolata* (benteak)	18.7	5.5	13.2
16	*Morus australis* syn. *M. indica* (mulberry)	17.8	4.7	13.1
17	*Pinus wallichiana* syn. *P. excelsa* (blue pine)	18.2	4.7	13.5
18	*Protium serratum* syn. *Bursera serrata*. (murtenga	20.1	7.0	13.1
19	*Swietenia mahagoni* (mahogany)	18.2	5.1	13.1
20	*Terminalia tomentosa* (laurel)	18.5	5.6	12.9
	Group C			
21	*Abies pindrow* (fir)	20.8	4.9	15.9
22	*Acrocarpus fraxinifolius* (mundani)	19.0	4.4	14.6
23	*Adina cordifolia* (haldu)	19.3	4.9	14.4
24	*Anogeissus latifolia* (axlewood)	19.8	5.0	14.8
25	*Buxus sempervirens* (boxwood)	19.8	5.1	14.7
26	*Castanopsis* spp. (chest nut)	19.3	4.8	14.5
27	*Cedrela toona* (toon)	21.0	5.3	15.7

1	2	3	4	5
28	*Dillenia pentagyna* (dillenia)	19.2	5.0	14.2
29	*Dipterocarpus alatus* (gurjan)	19.2	4.7	14.5
30	*Holoptelea integrifolia* (kanju)	20.5	4.8	15.7
31	*Hymenodictyon excelsum* (kuthan)	19.7	4.7	15.0
32	*Lagerstroemia speciosa* syn. *L. flos-reginae* (jarul)	20.0	5.0	15.0
33	*Lagerstroemia hypoleuca* (Andaman pyinma)	20.0	5.0	15.0
34	*Machilus macrantha* (machilus)	19.2	4.8	14.4
35	*Mangifera indica* (mango)	20.0	5.0	15.0
36	*Michelia champaca* (champak)	20.6	4.6	16.0
37	*Mitragyna parvifolia* (kaim)	20.7	5.0	15.7
38	*Phoebe hainesiana* (bonsum)	19.2	4.6	14.6
39	*Pinus roxburghii* syn. *P. longifolia* (chir)	20.8	6.2	14.6
40	*Planchonia valida* syn. *P. andamanica* (red bombway)	19.7	5.0	14.7
41	*Prunus padus* (bird cherry)	20.9	5.0	15.9
42	*Quercus semecarpifolia* (kharsu oak)	19.2	4.7	14.5
43	*Schima wallichii* (chilauni)	20.8	4.8	16.0
44	*Shorea robusta* (sal)	20.4	5.6	14.8
45	*Terminalia arjuna* (arjun), sapwood	19.6	4.8	14.8
46	*Terminalia bialata* (white chuglam)	19.8	5.1	14.7
47	*Terminalia paniculata* (kindal)	20.4	5.6	14.8
48	*Xylia xylocarpa* (irul)	20.9	5.9	15.0
		Group D		
49	*Acer compbellii* (maple)	21.6	4.9	16.7
50	*Betula utilis* (birch)	23.9	4.6	19.3
51	*Canarium euphyllum* (white dhup)	23.8	5.2	18.6
52	*Palaquium ellipticum* syn. *Dichopsis elliptica* (pali)	22.2	4.9	17.3
53	*Picea smithiana* syn. *P. morinda* (spruce)	22.2	5.4	16.8
54	*Pterocymbium tinctorium* syn. *Sterculia campanulata* (papita)	26.3	5.3	21.0
55	*Stereospermum personatum* syn. *S. chelonoides* (padri)	21.1	4.7	16.4
56	*Terminalia arjuna* (arjun), heartwood	22.5	6.1	16.4
57	*Terminalia procera* (white bombway)	21.6	5.2	16.4
58	*Vateria indica* (vellapine)	20.7	4.3	16.4

(Note :—Groups A, B, C and D contain timbers of which the differences in the E. M. C. at 96% R. H. and 30% R. H. lie between 11.5 and 12.5%, 12.6 and 14.0%, 14.1 and 16.0% and 16.1 and 21.0% respectively.)

The sorption curve for bamboo is generally similar to that for wood (Fig. XII-3).

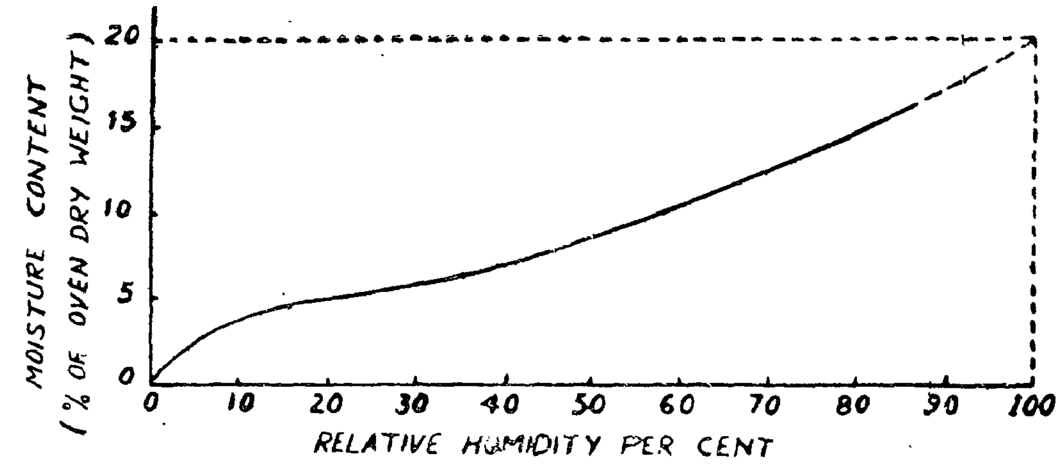


Fig. XII—3. Relation between E. M. C. and R. H. at 35°C for *Dendrocalamus strictus.*

Fibre Saturation Point (*F.S.P.*).—The point at which the cell cavities are completely free of 'free' water but the cell walls are completely saturated with 'bound' or 'adsorbed' water is called the *fibre saturation point*. It is the limiting value between these two forms of moisture (free water and bound water) and varies from 20 to 32% of the oven-dry weight for different species of wood.

Many important properties of wood show considerable change when free water is completely removed and the bound water begins to be removed from the cell walls, i.e., as soon as the wood is dried below the fibre saturation point. Some of these properties are enumerated below :

(i) The relative humidity reduction required to desorb a given amount of moisture from the wood shows an abrupt increase as the wood starts drying below F.S.P. (Fig. XII—4).

(ii) No shrinkage occurs until some bound water is lost, i.e., until the wood is dried below F.S.P. (Fig. XII—5).

(iii) Heat is evolved as dry wood adsorbs moisture in the cell walls upto F.S.P. The heat evolved is negligible for absorption of free water in the cell cavities.

(iv) Most strength properties, except height of drop in impact bending and in some cases the toughness, show a consistent increase with the first loss of bound water, or as the wood starts drying below F.S.P.

(v) The electrical resistivity increases only slowly with the loss of free water, whereas it increases very rapidly with the loss of bound water or when the wood is dried below F.S.P. Fig. XII—4, which gives the specific conductivity—moisture content relationship for wood, illustrates this point.

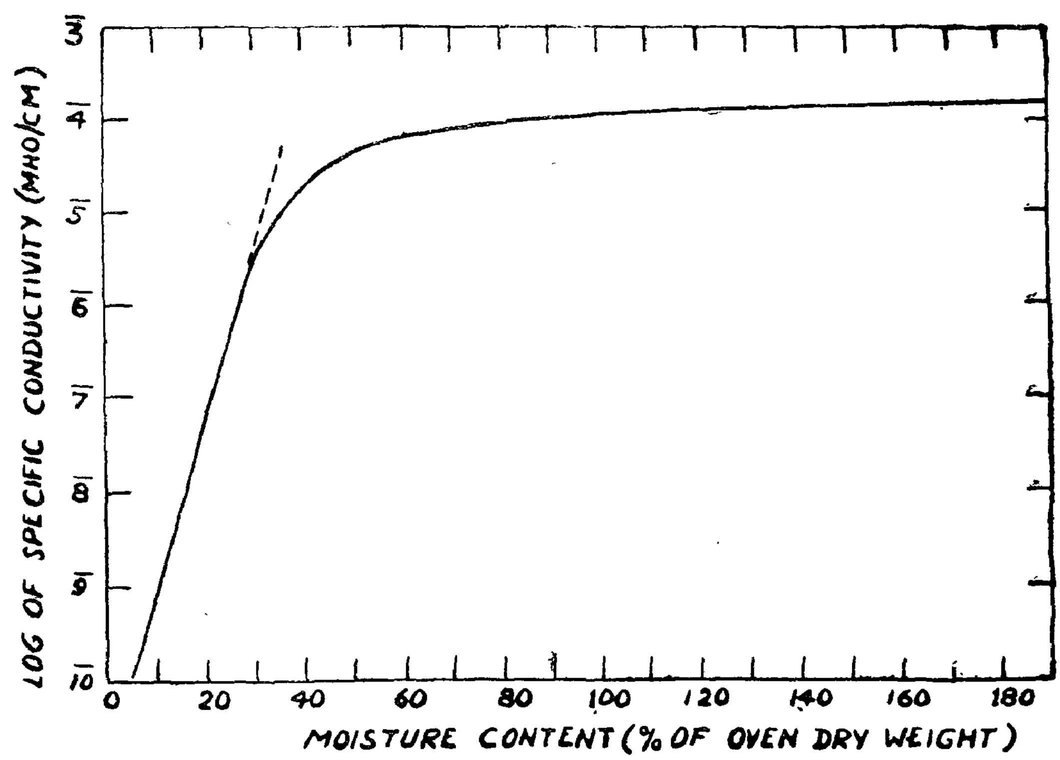


Fig. XII—4. Logarithm of specific conductivity of pine in fibre direction vs. moisture content. (Adapted from Stamm, A. J.)

Determination of Content

Testing of wood for its moisture content is often necessary to assess its conformity to specifications in commercial transactions, in the standardizations of its strength properties and in the various processes involved in wood utilization in timber industries, e.g., seasoning, preservative treatment, wood working, gluing, polishing, etc.

Moisture content of a large lot of boards, scantlings or finished products is tested, indirectly, on a few representative samples drawn from the lot. Statistical sampling procedure is worthwhile where the pieces are more or less of uniform characteristics such as species, size and quality. However, in lots containing mixed sapwood and heartwood, and/or a variety of sizes and quality of material samples should be taken from each variety of the material with special attention to the wettest material in the lot.

The methods which are generally adopted for determination of moisture content of wood are described below :

(1) *Oven-drying method.*—In this method, test sections 12 mm to 18 mm long along the grain are cross-cut from the selected sample pieces after rejecting at least a 25 cm portion from the ends. This precaution is necessary to eliminate the likely error due to the pieces being drier at the ends than in the middle portions. Immediately after cutting, loose slivers are removed from the test sections after which their weight are determined. They are then oven-dried by keeping in a ventilated oven maintained at a temperature 100° to 105° C. Drying under such conditions removes practically all the water contained inwood except traces of bound water which may be neglected for all practical purposes, being less than 0.5 per cent. A practically constant weight, called the oven-dry weight, is attained in the test sections by oven-drying for 24 to 48 hours. Fortunately, at these temperatures, heating for short periods does not cause sufficient thermal degradation as to introduce an appreciable error in the oven-dry weight.

After determination of the oven-dry weight the moisture content of each test section is calculated by the formula :

$$\text{Moisture content} = \frac{\text{Wet weight} - \text{Oven-dry weight}}{\text{Oven-dry weight}} \times 100$$

Let us consider an actual example. A test section with an initial weight of 44.4 grams, weighed 38.4 grams after 24 hours drying in an oven and 38.3 grams four hours later still. Accepting the later of these weighings as the oven-dry weight, the moisture content of the sample was

$$\frac{44.4-38.3}{38.3} \times 100 = 15.9\%$$

The oven-drying method is liable to following errors :

(i) The final weight varies slightly with the atmospheric humidity.

(ii) The final weight attained between 100° to 105°C also varies slightly with temperature.

(iii) Some error, though slight, is caused by the change of moisture content which occurs as a result of exposure of the test sections to the atmosphere, particularly when cutting and weighing green wood sections or weighing sections hot from the oven.

(iv) Sawing of the test section, if done with a dull saw, causes appreciable error.

The cumulative effect of all these errors on the determination of moisture content generally does not exceed 1% absolute.

Though the oven drying method is rather elaborate, requires a laboratory and necessitates cutting the wood sample, it is the method adopted as standard for most purpose on account of its accuracy and reliability.

(2) *Distillation Method* : The oven drying method does not give correct values of moisture content of wood having volatile oils and resinous matter. During oven drying, along with the moisture some volatile oils also distil off, thereby giving considerably higher values of moisture content. Another trouble is that as such woods go on losing weight even after several days in the oven, it is difficult to fix dry weight of the oven drying test section.

The best method for finding moisture content of wood, containing appreciable quantities substances that volatilise at temperatures below or at the boiling point of water, is by distillation. In this method, the sample of wood to be tested is first converted into small chips. The chips are then boiled in an organic, liquid, immiscible with water and having a boiling point higher than that of water, and the vapours are condensed in a receiver. The water separates out in the condensate and its volume is measured, for which usually there is an arrangement in the receiver itself. The liquid ordinarily used is toluene. The moisture content is calculated from the measured amount of water in the condensate and the final weight of the dry chips in the distilling flask.

When compared to oven drying, distillation method is more complicated. It needs constant supervision, as toluene is inflamable. The apparatus needs careful handling. It enables only a single sample to be tested at a time, which makes the method very time-consuming.

(3) *Electric Moisture Meters.*—The oven drying method of finding moisture content of wood rather difficult to adopt in common commercial practices such as field inspection of timber, quality control in the processing of timber and manufacture of wood products. A portable instrument, robust, easy to operate, capable of giving direct and quick readings, preferably on the spot, and reasonably accurate would be ideally suited for such work. Electric moisture meter is one such instrument which satisfies most of these requirements.

Different makes of the electric moisture meters are available. They are generally of two different types: (i) Electrical Resistance Meters, which are based on the effect of moisture content on the electrical resistance of wood, and (ii) Capacity Reactance Meters, which determine the moisture content through its effect on the dielectric constant (which indicates the polarization of the medium under an applied electric field) or the power factor (which is the ratio of the resistive component of the current to the total current) of wood in a high frequency current. The first type is more popular.

(i) *Resistance Meters.*—The working of these meters is based upon the fact that changes in moisture content cause an appreciable change in the electrical resistance of wood (fig. XII—4). From the green state to the fibre saturation point the change in resistance is rather small, but when the moisture content falls below the fibre saturation point the resistance increases enormously. Below 8% moisture content the magnitude of the resistance of wood becomes very high, and on account of the leakage in insulation in the measuring circuit the results obtained are not reliable. Consequently, measurements with resistance meters are limited to moisture content values above 8%. The upper practical limit is slightly below the fibre saturation point, although some instruments are calibrated to give higher values also.

The resistance is measured by any one of the several methods. In one of these, the small direct current which flows through the wood is amplified. The larger current thus obtained is balanced against the current from a set of dry cells. The latter is controlled by a variable resistance. The adjustment of resistance is made by a dial which is calibrated to give moisture content directly. A needle type of galvanometer serves as an indicator for adjustment. The instrument is calibrated to read correct moisture contents for selected common species of timber at a specified temperature. Moisture content obtained by oven-drying is taken as the standard for calibration work.

The resistance meters are usually provided with steel needles or knife-edge type of electrodes for passing the current through the wood. These electrodes are mounted, a fixed distance apart, on an insulated handle and can be driven into the wood by hammering the handle. The length of the electrodes varies from 6 mm to 8 mm.

Besides finding the moisture content in the case of uniform moisture distribution, such electrodes can also give the average moisture content of timber having a normal drying gradient, provided all parts of its section are below the fibre saturation point. In such a distribution, the actual moisture content at a depth one-fifth of the thickness of the material is equal to the average moisture content of the section. Consequently, electrodes inserted to this depth will give the average moisture content of the whole section. The electrodes generally provided with resistance meters can give service for material from 6 mm to 38 mm thick. For thicker stock, special deep-probe electrodes or even nails can be used.

The change of electrical resistance of wood with changes in moisture content is so great that it largely masks the effects due to variation in specific gravity and natural ash content (water-soluble extractive fraction) from species to species. A two-fold change in specific gravity and the maximum normal

variation in ash content thus will not change the moisture content by more than a small per cent absolute. Such an error is not serious for certain applications. Because of this, calibration for a single species is all that is needed. When more precise results are desired, correction figures should be determined and applied separately for each species.

Though a very valuable aid for control purposes, the resistance meters are sometimes liable to give widely inconsistent readings which can be disconcerting to an operator who is not well experienced. The meters do not give reliable results with timber which has been treated with water-soluble salts or surface-coated. They cannot be used on material hot from the kiln unless temperature corrections are applied. When the surface of the timber is wetter than the interior, the meter will record a much higher moisture content than the average. It is, therefore, liable to be erratic whe used on dry timber that has become wet by rain or exposed to damp conditions that have caused the surfaces to become wet. Irregular moisture gradients in the thickness and moisture pockets in the interior also introduce errors in the reading. In wet weather the surface insulation of the moisture meter becomes wet and tends to leak current, thus seriously interfering with the accuracy of the instrument. The resistancy meter is thus not as reliable and accurate as the oven-drying method for determining moisture content of wood. Even after all precautions are, taken and corrections applied, errors upto 2% absolute in readings are likely. Used intelligently, however, it is an instrument which can make a significant contribution towards raising the standard of timber industries.

(ii) *Capacity Reactance Meters.*—Capacity reactance meters, which measure either the dielectric constant or the power factor, have a distinct advantage over resistance meters in that only reasonably good contact is needed and no permanent pin marks need be made on the wood. Changes in dielectric constant and power factor with moisture content are, however, relatively small compared with resistance changes. Because of this, specific gravity and ash content variations have a much greater effect upon the moisture content determinations. Frequent calibration to correct for variation in the properties of the wood handled is essential to obtain even reasonably accurate results. As there is considerable variation in sp. gr. between different species and also within the species to a certain extent, this meter is not very suitable for timber industries. This method is more suitable for paper or fabric, as the specific gravity of a particular product being made is normally quite constant, making possible a more exact calibration of the instrument.

Shrinkage of Wood

Shrinkage and its accompanying effects of warping, checking and splitting constitute wood's most troublesome physical property. A proper understanding of this phenomenon is, therefore, necessary to minimise its effects and to reduce its magnitude.

The reduction in size, or shrinkage on loss of moisture, is expressed as percentage of the original green dimension or volume, depending upon whether linear or volumetric shrinkage is being measured. The terms "longitudinal", "tangential" and "radial" shrinkage are used to describe the linear shrinkage in the respective reference direction.

Shrinkage in wood occurs when the hygroscopic, adsorbed or bound water is removed from the cell walls. The desorption of water from the amorphous zones and peripheral surfaces of crystallites within the microfibrillar structure sets up surface tension forces over the areas of contact of water with the cellulose chains that tend to draw the chain together, resulting in shrinkage. The considerably greater lateral surface fo adsorption of the microfibrils compared to the end surface (because of their long threadlike shape), and the preferred orientation of the bulk of the microfibrils in the cell wall in the general direction of the cell axis or the grain, cause the bulk of shrinkage to occur transversely to the grain direction. Thus, the longitudinal shrinkage of wood of normrl growth is negligible for practical purposes, ranging from about 0.1 to 0.3 per cent, in contrast to transverse shrinkages of 1.1 to 16.8 per cent. An exception is "reaction wood" ("compression wood" in softwoods and "tension wood" in hardwoods), in which the orieetation of microfibrils in the cell wall apprciably deviates from the direction of the cell axis or the grain, and longitudinal shrinkage may be quite appreciable.

Wood shows anisotropicity (i.e., variation in properties in different directions) in transverse shrinkage also, the shrinkage being about 3.3 to 16.8 per cent in the tangential direction and about 1.1 to 6

per cent in the radial direction. Several widely different reasons have been put forth to explain this difference, such as the possible restraining effect of ray cells on shrinkage along the radial direction, difference in the density and shrinkage of summer wood and spring wood, difference in their relative layout in the tangential and radial direction, etc. The most important reason, or combination of reasons, for this phenomenon is, however, still uncertain.

Theoretically, volumetric shrinkage should be equal to the sum of tangential and radial shrinkages in a piece, when the values are expressed as percentages of the original green size. Experimentally determined values, however, often show slight deviations from this rule.

When very thin sections of green wood are dried without developing appreciable moisture gradients and associated drying stresses, there is practically no shrinkage in external dimensions until the fibre saturation point is approached. Appreciable shrinkage in external dimensions sets in only when the wood is dried below the fibre saturation moisture content.Thick sections of most species may however exhibit a small amount of shrinkage at a moisture content somewhat above the fibre saturation point. This is due to the development of appreciable moisture gradients in drying of such sections, with the result that the surface portions of the section fall below the fibre saturation point and tend to shrink before the average moisture content has reached fibre saturation point.

Fig. XII—5 illustrates the relationship of volumetric shrinkage to moisture content of wood, which is approximately linear below the fibre saturation point, indicating that shrinkage occurs approximately proportional to the moisture lost below this point. The relationship is similar for tangential and radial shrinkage. Extrapolation of the linear portion of the volumetric shrinkage—moisture content plots, for thin cross sections of wood, to zero shrinkage gives moisture content intercepts which are reasonably close approximations of the fibre saturation point.

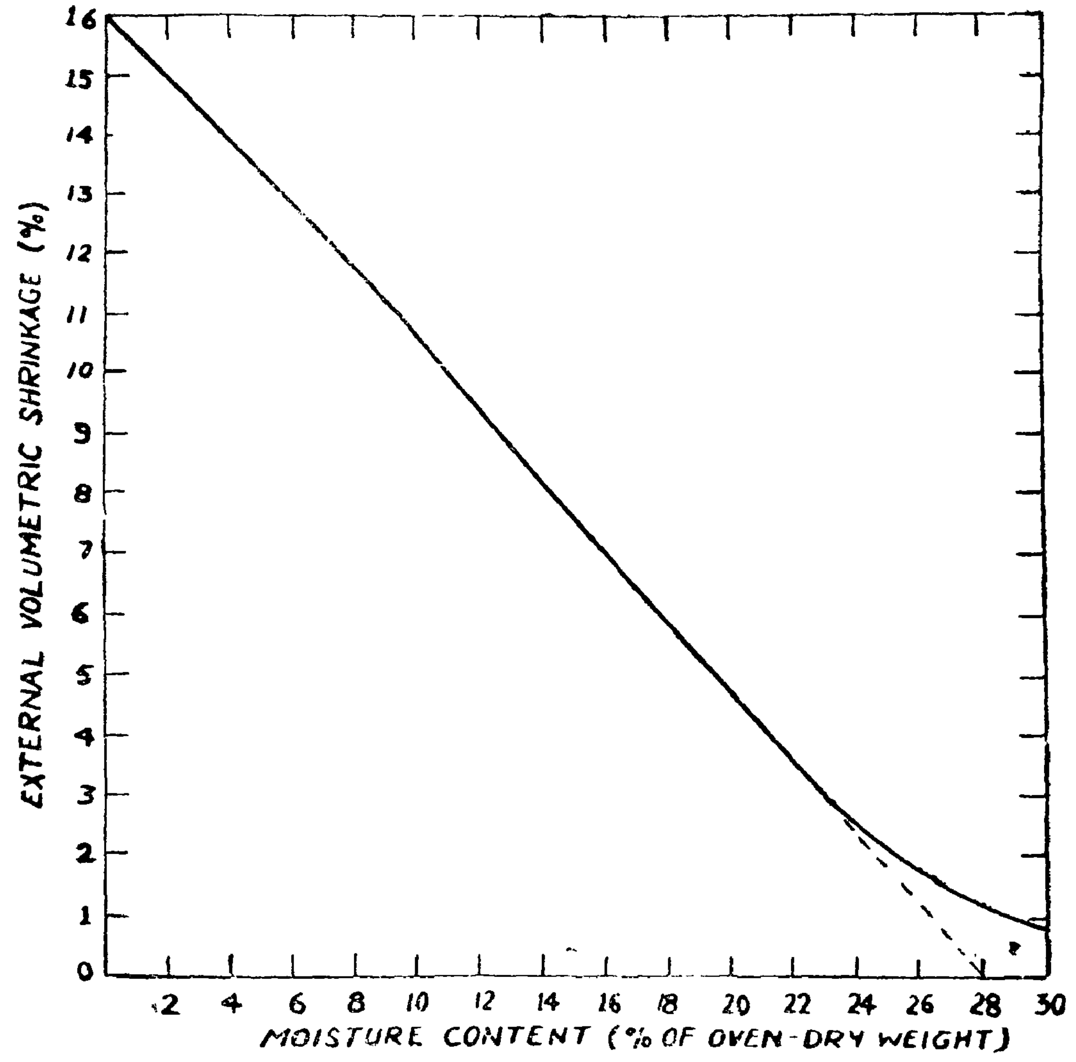


Fig. XII—5. External volumetrice shrinkage—moisture content relationship of 2.2 cm thick boards of pine, specific gravity 0.63 on swollen volume basis.
(Adapted from Stamm, A. J.)

Sizeable specimens of certain species, such as the Australian eucalypts, red oak etc., tend to shrink at moisture contents far above the fibre saturation points, especially when kiln dried at high temperatures under high relative humidity conditions. This is illustrated for the Indian species toon (*Cedrela toona*) in Fig. XII– 6. This abnormal shrinkage is due to collapse during drying. A similar behaviour is exhibited in circumferential shrinkage of bamboo culms in drying, even at low temperatures (Fig.XII—7).

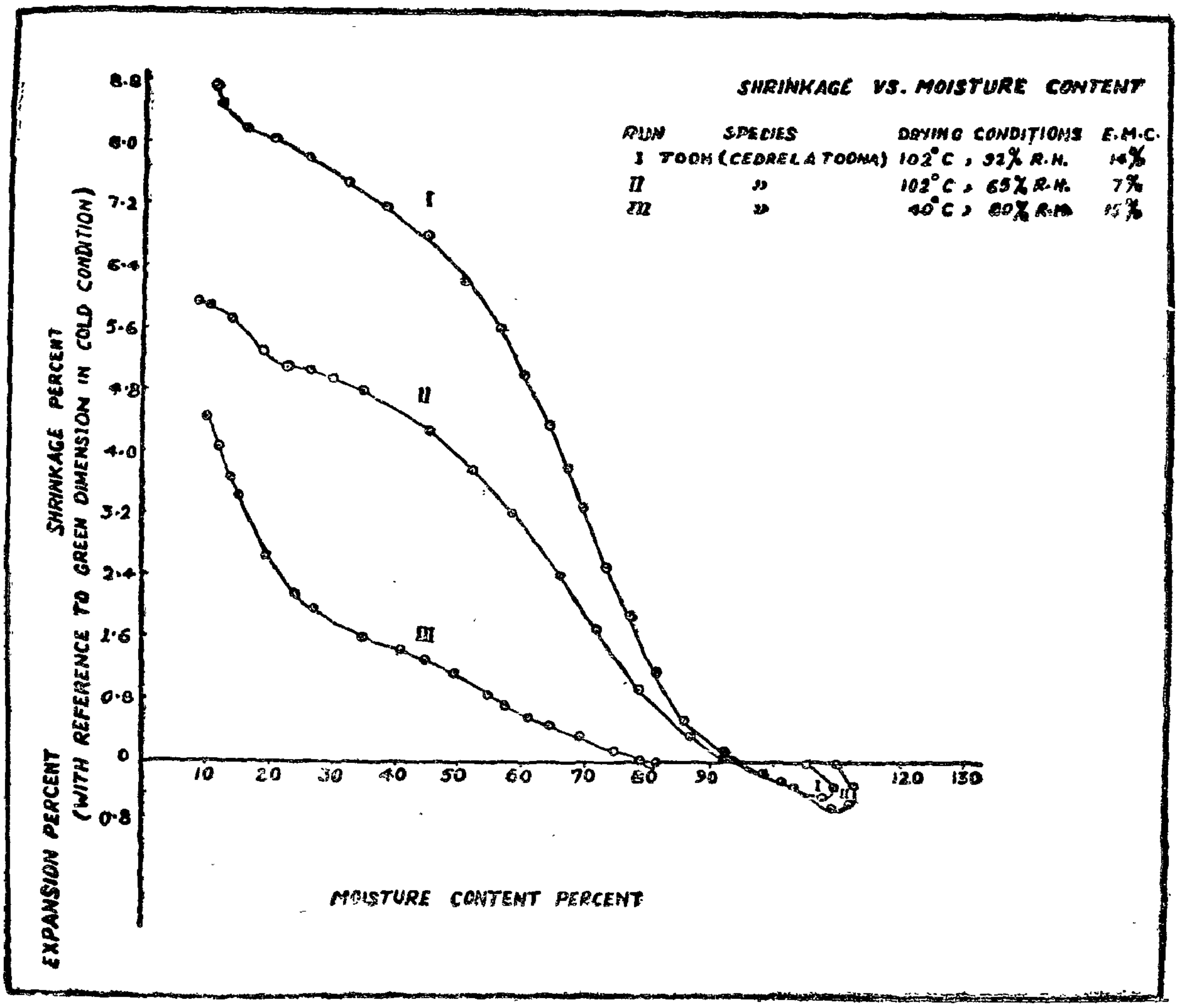


Fig. XII—6, Shrinkage—moisture content relationship for toon (*Cedrela toona*) under high temperature drying.

The extent of shrinkage varies widely between different wood species. As a very general and approximate rule, the volumetric shrinkage of wood may be taken to increase proportionately with the increase of specific gravity on an oven-dry weight-swollen volume basis. Incidentally, this implies that the the volume change due to moisture loss is confined to the cell wall substance in a piece of wood and the permanent voids of the cell cavities remain unchaged in size during drying.

In spite of its general validity, a good deal of deviation from the above relationship exists in certain species. Wood, the high water soluble extractives content, shrink less than what would be expected from the proportional relationship with specific gravity. The extractives are left deposited in the cell walls as water evaporates from the the cells, leaving the cell walls swollen by an amount equal to the volume of dry extractives. This is generally also accompanied by a concomitant decrease in the fibre saturation point. Stresses which develop during the drying of the wood also increase or decrease the shrinkage relative to the specific gravity relationship, through the development of permanent compression or tension set which alters the size of the cell cavities. The kind of permanent set which is preponderant depends upon the relative strength of the species in compression and tension accross the grain. Species susceptible to collapse during drying generally shrink more than what may be expected on the basis of the specific gravity.

Appendix I gives, in addition to the other information, average, maximum and minimum species figures of total tangential, radial and volumetric shrinkage in drying from the green to the oven-dry condition for some of the common commercial Indian woods. The determinations were made on small clear specimens of green wood, measuring 10 cm along the direction of shrinkage measurement

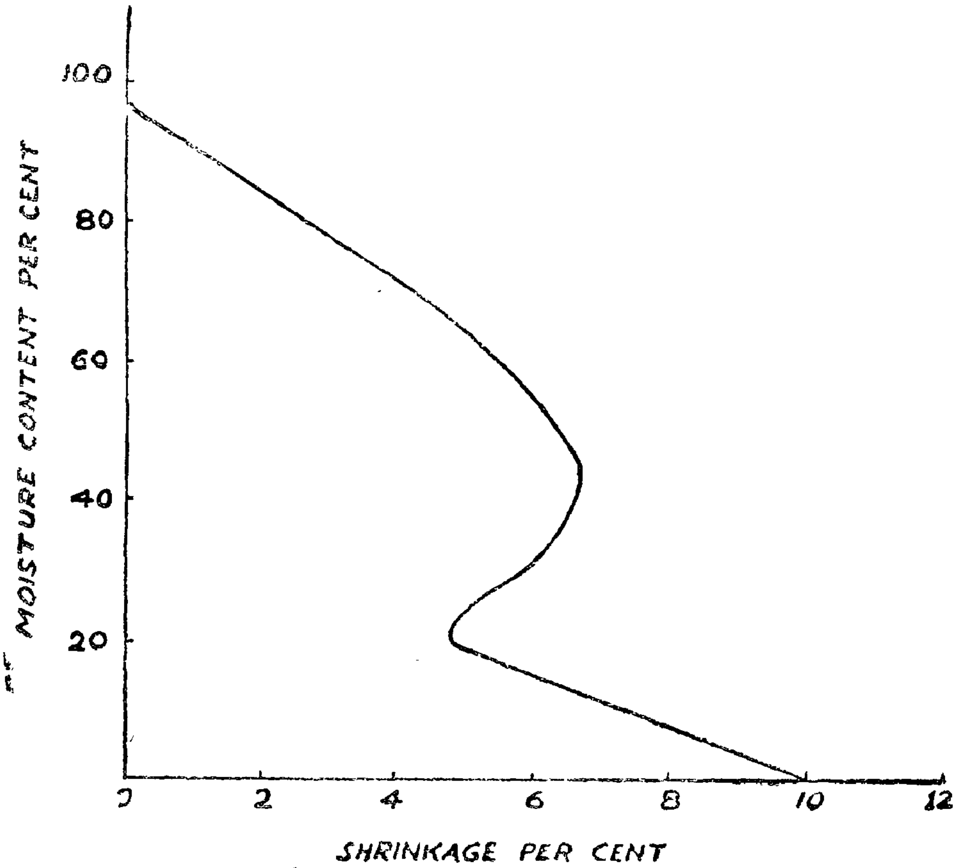


Fig. XII—7. Moisture content—shrinkage trend in *Dendrocalamus strictus* from freshly felled ot oven-dry state.

(tangential or radial) and 25 mm×25 mm in cross-section slowly direct under room conditions still "air-dry" and finally oven-dried. Ratio of the tangential to radial shrinkage for these species can be worked out. Table X—5 lists comparative Index figures (taking the one for teak as 100) for retention of shape in service, of thirty defferent timber species, which have been arrived at by combining the volumetric, tangential and radial shrinkage and the ratio of tangential to radial shrinkage, after applying suitable weighting and adjusting factors. The adjusting factors are applied to bring the various properties combined to the same order of magnitude and are based on the experimental result obtained with teak. The weighting factors have been fixed after consideration of the relative importance of the different shrinkage properties in causing deformation in timber, and are largely a matter of judgment. It may however be meantioned that, in practice, steadiness of timber is also influenced by a number of other factors which have not been taken into account in the above index. Some of these factors are the rate at which the timber allows moisture exchange with the atmospheric conditions (which varies with the species and cross sectional dimensions), the ratio of width to thickness, natural unevenness of grain, slope of grain introduced by faulty sawing, presence of knots, etc.

Effects of shrinkage.—The combined effect of radial and tangential shrinkage on the shape of various sections in drying from the green condition is illustrated in Fig. XII—8. Wood that contains irregular grain, deviation of grain due to knots or cross grain (i. e., inclination of grain to the sides of the piece) introducted through careless sawing, will shrink more longitudinally (i.e., lengthwise) than the straight-grained wood. Local shrinkage in such pieces may cause various forms of longitudinal distortion such as bow, spring, twist or crookedness (Fig. XIII—7).

Misfitting of doors and windows, shrunken panels loosening of joints and fastenings and nail-pops are common instance of defects due to shrinkage and swelling in timber structures and woodwork. Even seasoned wood, i.e., wood which has attained virtual moisture content equilibrium with the prevailing atmospheric conditions in service, is liable to exhibit the above effects to some extent on account of the fluctuations in moisture content with seasonal changes in atmospheric relative humidity, details of which are discussed later. The normal seasonal changes of moisture content are, however, not enough to cause serious change in shape and size, if the wood is thoroughly seasoned and the woodwork is properly designed.

The tendency of seasoned wood to shrink with loss of moisture and swell with reabsorption of moisture under climatic fluctuations is rermed "movement" or "working". The experienced

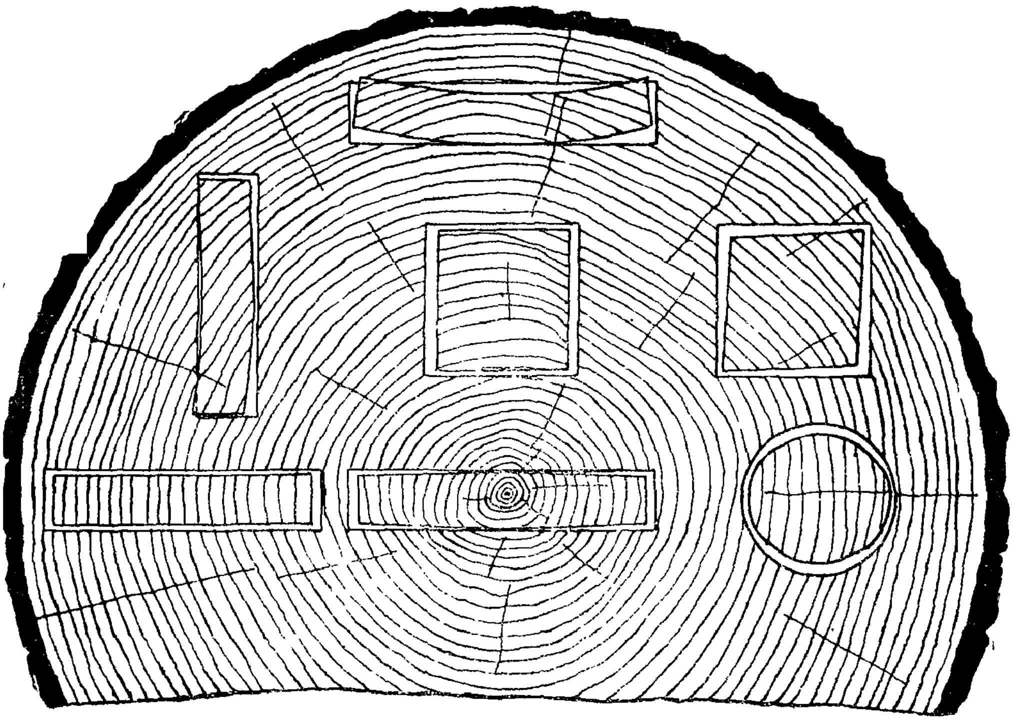


Fig. XII—8. Characteristic shrinkage and distortion of flats, squares and rounds as affected by the direction of the annual rings. Tangential shrinkage is about twice as great as radial.

(Adapted from "wood Handbook" No 72 U. S. Deptt. of Agri.)

joiner and cabinet-maker allows for the movement of wood, based on his experience of the kind of wood he is using and the use to which it is to be put. However, since the shrinkage-moisture content relationship for wood is approximately linear below the fibre saturation point, rough estimates for the movement of the timber under a given climatic conditions in this country may be calculated on the basis of this relationship, by using the maxmum and minimum moisture content figures of wood in different climatic zones as given in Table XII—2, the total shrinkage figures for the species used from Appendix I, and assuming a reasonable value for the fibre saturation point.

TABLE XII—2

Maximum and minimum equilibrium moisture contents of seasoned timber at some important stations in India (From IS : 287-1960)

Locality	Average of moisture contents attained by six representative timber species	
	Max. per sent	Min. per cent
Tiruchirappalli	13.9	9.2
Coimbatore	13.3	9.7
Ishapore (Calcutta)	14.9	9.9
Perambur (Madras)	13.8	9.7
Parel (Bombay)	15.5	10.7
Kharagpur	13.8	8.4
Jodhpur	10.9	5.1
Dehra Dun	14.2	7.1
Bareilly	15.8	6.0
Kanpur	14.7	5.4
Ajmer	11.3	4.2
Jabalpur	18.8	4.3

The troubles arising from shrinkage and swelling of wood can be minimised in certain cases by adopting suitable constructional designs. Constructional methods may be considered that minimise the use of wood across the grain in the direction in which the consequences of shrinkage are likely to be most critical. Wide plain surfaces, such as table tops counter tops and panels may be cross-banded. Large panels should be so designed and installed that they are free to move across the grain. When wide moulding is matched at 90 degrees, the opening of the joint due to swelling can be prevented by adopting a cribed joint. Dowels used in wood-work should be of wood which matches the main member in kind, density, direction and moisture content. For precision jobs, apart from choice of a species having low shrinkage, selection of material of strict specifications with regard to straightness of grain and freedom from knots, and its thorough seasoning before use, are important considerations. Radially sawn planks are less liable to warp and change size in service than tangentially sawn planks.

Moisture content for seasoned timber

Fig.XII—2 depicts the moisture content of wood conditioned to equilibrium with different relative humidities at six different temperatures, as determined under laboratory conditions of controlled temperature and relative humidity. Wood, under practical conditions of use, seldom a tams true equilibrium of moisture content, as the atmospheric temperature and relative humidity keep on fluctuating. These atmospheric change range from the usual daily to marked seasonal variations. Consequently wood, even though initially dried from the green condition to approximate equilibrium with the prevailing atmospheric condition (i.e., seasoned) continues to undergo fluctuations in moisture content because of its tendency to come to a balance with the surrounding atmospheric condition.

A detailed study has been made of the seasonal variation of moisture content of seasoned wood with the object of recommending optimum moisture contents to which timber should be seasoned for use in different climatic conditions in India. Samples, 60 cm×23 cm × 2.5 cm in size, of seasoned wood were kept exposed to the atmospheric conditions in a covered verandah at twelve stations in different parts of the country, and their moisture contents were recorded periodically over a period of two years.

A typical moisture content record for toon (*Cedrela toona*) and teak (*Tectona grandis*) samples along with the record of atmospheric relative humidity at Kanpur is given in Fig. XII—9. The average moisture content for six species included in the tests attained a maximum of 14.7 per cent during the rainy season and a minimum of 5.4 per cent during the dry summer at this station. The optimum moisture

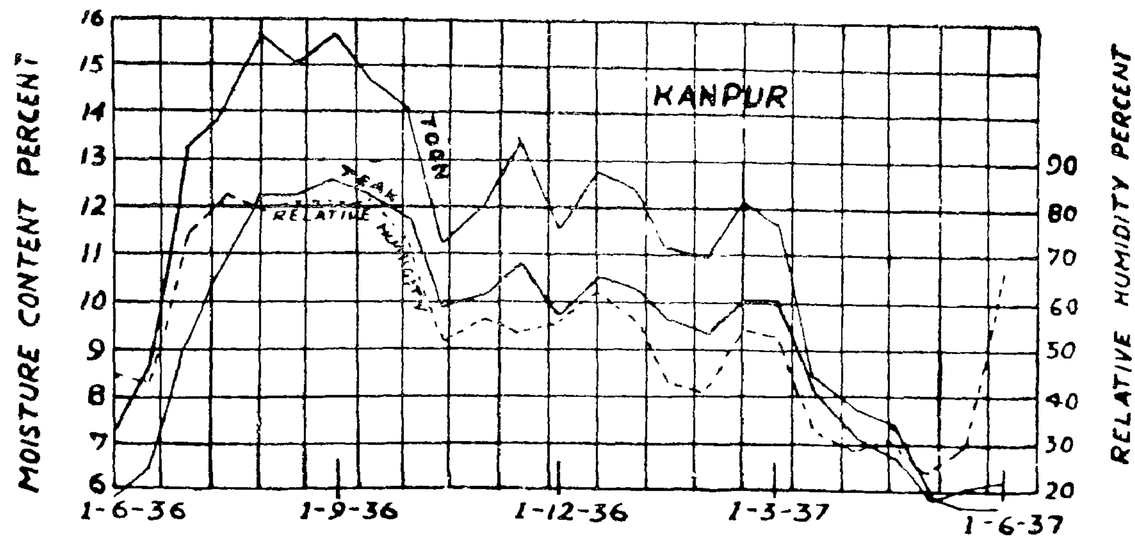


Fig. XII—9. Seasonal changes in moisture content of samples of toon and teak at Kanpur for a period of 12 months.

content to which wood should be seasoned for use in this climate would be the mean between the maximum and minimum, i.e., $\frac{14.7 + 5.4}{2}$ or about 10 per cent. Woodwork fabricated from wood having this moisture content will give the least trouble from seasonal variations in moisture content.

The maximum and minimum moisture contents attained by the seasoned timber under cover at the twelve stations are given in Table XII-2. On the basis of this data, and the meteorological data available for these stations, the country has been divided into four climatic zones from the point of view of the optimum moisture content for seasoned timber. The zones have been distinguished according to average annual relative humidity as follows:

Zone I	Average annual R.H. less than 40 per cent.
Zone II	Average annual R.H. less than 40-50 per cent.
Zone III	Average annual R.H. less than 50-67 per cent.
Zone IV	Average annual R.H. more than 67 per cent.

The optimum moisture contents for seasoned timber for use under indoor conditions in Zones I, II, III and IV have been determined to be 8, 10, 12 and 14 per cent respectively. Timber intended to be used for precision jobs should conform to these moisture contents. It is desirable that for the best service, timber in thin sections should also be seasoned to the above mentioned moisture contents, as moisture content in such sections is liable to change with fluctuation of atmospheric humidity more rapidly than in thicker sections. Somewhat higher moisture content may be allowed in case the timber is to be used for jobs where the requirements with regard to precision of shape and size in service are less exacting, or in case it is to be used in thick sections.

The recommended moisture contents for wood for different purposes in different climatic zones are given in Table XII-3.

Movement of Moisture in Wood

When wood is dried, the surface zones usually dry in advance of the interior because of direct evaporation of the moisture at the surface into the surrounding space. As a result, a moisture gradient is set up which causes the moisture to move from interior to the surface. The rate of movement of moisture through wood, in conjunction with the externally applied drying conditions, determines the drying rate and, to a considerable extent, the behaviour of wood in the drying process.

The movement of moisture through wood is a complex phenomenon, as this not only involves movement of water in a number of different forms but the channels effective for their movement also differ. The mechanism of movement of water in its different forms is also different. Below the fibre saturation point, water can move as vapour through the cell cavities and as bound water through the finer capillaries of the cell wall. This combined movement of vapour and bound water below the fibre saturation point is believed to take place by diffusion. Above the fibre saturation point, free water may move through the cell cavities *via* the intercommunicating pit openings by capillarity in a mass flow. Permeability of wood is involved in the mass flow of free water.

Diffusion of Bound Water and Vapour in Wood Below the Fibre Saturation Point

Diffusion is the phenomenon involving the spontaneous movement of moisture through wood from a zone of higher moisture content to a zone of lower moisture content in an effort to equalize the moisture content. The motivating force for diffusion of bound water through the cell walls below the fibre saturation point is the hygroscopic gradient that results from a difference in moisture content. The driving force for water vapour diffusion through the cell cavities below the fibre saturation point is the vapour pressure gradient that is associated with the moisture content gradient.

TABLE XII—3

Maximum Permissible Moisture Content of Timber for Different Uses
(From IS: 287-1960)

Use	Moisture Content Per cent Max.			
	Zone I	Zone II	Zone III	Zone IV
Aircraft	12	12	14	15
	(Minimum permissible moisture content in all zones shall be 10 per cent)			
Agricultural implements	12	14	16	16
Ammunition boxes	10	12	14	15
Artificial limbs	8	10	12	12
Automobile bodies :				
(a) 50 mm and above in thickness	10	12	14	14
(b) thinner than 50 mm	8	10	12	12
Beams and rafters	12	14	17	20
Boot lasts	10	12	14	16
Box shooks	12	14	16	18
Carts and vehicles (not motor driven)	10	12	14	16
Cooperage	10	12	12	14
Doors and windows :				
(a) 50 mm and above in thickness	10	12	14	16
(b) thinner than 50 mm	8	10	12	14
Electrical industry	10	12	14	15
Flooring strips for general purpose	8	10	10	12
Flooring strips for tea gardens	12	12	14	16
Furniture and cabinet making	10	12	14	15
Handles	12	12	14	15
Pattern making	8	10	12	14
Railway carriage building :				
(a) 50 mm and above in thickness	10	12	14	14
(b) thinner than 50 mm	8	13	12	12
Rifle parts and gun stocks	8	10	12	12
Shuttles and bobbins	8	10	12	12
Sports goods, umbrellas and walking sticks	10	12	14	16
Ship and boat building :				
Deck	10	12	12	14
Frame	12	14	16	18
Planking	12	14	14	16
Timber meant for further conversion, posts and poles	20 per cent in all zones, moisture content being determined within a depth of 12 mm from the surface and excluding 30 cm from each end			
Toys, turnery, carving, clocks, brushes, picture frames, brooms, cigar boxes, pens, pencils, mathematical and musical instruments and household goods	8	10	12	12

Vapour diffusion in the cell cavities takes place far more easily than bound water diffusion in the cell walls. From this one might conclude that continuous vapour diffusion through the cell cavities *via* the inter-connecting pit membrane openings should contribute considerably to the total flow, but such is not the case, The minute pores through the pit membranes are much too small and scarce to provide for appreciable vapour diffusion. Bound water diffusion across the cell wall and then vapour diffusion across the cell cavity to the next cell wall, in series, is the mode of movement of major importance.

Since the rate of diffusion across the cell cavitiy is very much greater than that across the cell wall, the over all ease with which diffusion occurs, which is expressed as *diffusion coefficient*, is closely dependent upon the amount of cell-wall material that must be penetrated. Thus the diffusion coefficient varies inversely as the density of the wood. And since continuous vapour diffusion *via* the pit membrane pores plays only a minor role, permeability which controls the rate of mass flow is a minor factor in diffusion of moisture below the fibre saturation point. Thus the impermeable heartwood of a given species should dry from fibre saturation to equilibrium moisture content in virtually the same time as the highly permeable sapwood, provided they are of the same density. But in drying from the freshly cut green condition, free water is involved; and thus permeability becomes a very important factor.

Not only wood density but also the drying temperature is of great importance in determining the rate of diffusion. The diffusion coefficient, or ease of diffusion, has been found to increase rapidly with temperature in the same proportion as the saturation vapour pressure of water increases.

The moisture content being the ratio of weight of water to weight of dry wood substance, for a given fall in moisture content a greater weight of water is lost from the drying surfaces of thicker planks and also from denser planks, since the weight of dry wood (i.e., dry cell-wall substance in a plank of given length and width is directly proportional to both its thickness and its density. Thus a greater loss of water, and therefore a longer drying time, is required to obtain a given reduction in moisture content with thicker or denser planks. Furthermore, as already mention, since the rate of mositure diffusion is also inversely proportional to the amount of cell wall that must be traversed, and the amount of the cell wall in a plank is directly proportional to the density and the plank thickness, the time required for a given reduction in moisture content should be proportional to the square of the density and also to be square of the plank thickness. This is because of the fact that if density or thickness increases it is both more difficult for a given weight of water to reach the plank surface and also a greater weight of water is required for a given reduction in moisture content.

The above are simplified "rules of thumb", applicable to diffusion controlled drying and when drying principally involves movement of moisture across the grain, It has been empirically found that a more practical rule of thumb is that the total drying time is directly proportional to both the board thickness and density raised to the power 1.5.

In a plank, the area of lateral surfaces is many times larger than that of the end surfaces, and the distance for moisture to move out is also much shorter along the cross sectional dimensions than along the length. Thus, in drying of commercial sizes moisture predominantly moves perpendicular to the grain, except when the timber is in short lengths.

The diffusion of moisture through wood also depends upon its structure. The rate of diffusion along the grain is several times faster than that across the grain. Across the grain, radial diffusion is usually only slightly faster than the tangential diffusion.

Experimental evidence indicates that the rate of moisture diffusion from the fibre saturation point to the oven-dry condition is not constant. According to some research workers, the diffusion coefficient decreases continuously with a decrease in moisture content below fibre saturation, while according to others the trend is more complicated,

Experience has shown that diffusion-controlled moisture gradients in wood in drying below the fibre saturation point are parabolic in form and that the moisture distribution can be expressed by the equation:

$$P = \frac{3}{2}(M-E)+E$$

Where P is the moisture content at the mid-thickness of the plank, M is the average moisture content in the whole section and E is the moisture content at the surface. The equation applies only when all parts of the section are below the fibre saturation point and the distribution is a regular drying gradient.

Movement of free water above the fibre saturation point

The diffusion of moisture below the fibre saturation point has been discussed above. Wood, however, normally has to be dried from well above the fibre saturation point, which involves movement of free water. The movement of free water is a phenomenon quite different from the diffusion of moisture below the fibre saturation point. It is similar to the flow of water in pipes, and requires that both a pressure be exerted and a continuous passageway of voids be available if flow has to occur *en masse.*

Even freshly cut green wood has a moisture content well below the maximum moisture content for most species, so air bubbles and curved menisci would be expected to occur in most, if not all, of the cell cavities. When drying starts, the evaporation at the surface of wood causes the air bubbles in the cavities of interior cells to expand and total "bubble pressure" (the resultant of air pressure, vapour pressure and capillary tension) falls. The bubble pressure in the cells nearer the surface falls more than that in the interior cells. A bubble pressure gradient is thus set up, which tends to cause the flow of free water from the interior to the surface. The permeability of the finer capillaries, inter-connecting the cell cavities, controls the flow of free water under such conditions. The importance of free water flow in drying wood from above the fibre saturation point is discussed below.

Sooner or later after drying has started, the rate of free water flow to the surface falls behind the rate of surface evaporation, and the surface moisture content begins to fall. In the majority of commercially dried woods, the surface moisture content falls soon below the fibre saturation to the equilibrium moisture content, if not immediately after the drying begins. In the dry surface zone moisture now moves both as vapour and as bound water by diffusion, but free water continues to flow to the fibre saturation boundary in the wet interior zone. The ease with which this free water can flow to the fibre saturation boundary considerably influences the form of moisture gradient which develops in the section at this stage of drying. Consider the examples of moisture gradients illustrated in Figs. XII 10 (a)&(b). The first gradient illustrates the common condition where the wood is moderately permeable. In this case the surface moisture content has approached equilibrium moisture content and a bound water gradient continues almost smoothly past fibre saturation into a free water gradient. The resulting moisture gradient is approximately parabolic. The second gradient illustrates the situation in highly impermeable wood which has no continuous void structure and thus no flow of free water is possible. In this case, free water can be brought to the surface only by diffusion below fibre saturation in the dry zone.

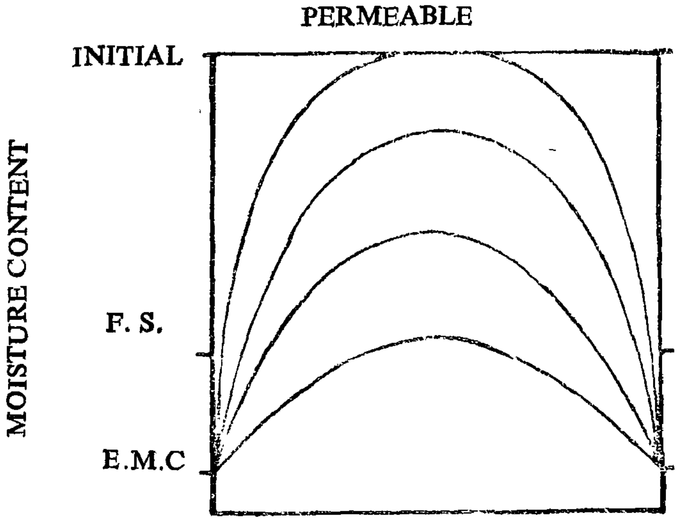
The steeper the moisture gradient in the dry zone at the wood surface the faster is the drying. At the same stage of drying, i.e., after the same amount of moisture has been lost, the slops of the moisture gradient at the wood surface will be appreciably less or highly impermeable word than for moderately permeable wood, as illustrated in Fix. XII-10(c). Thus a moderately permeable wood will dry faster.

Permeability of wood

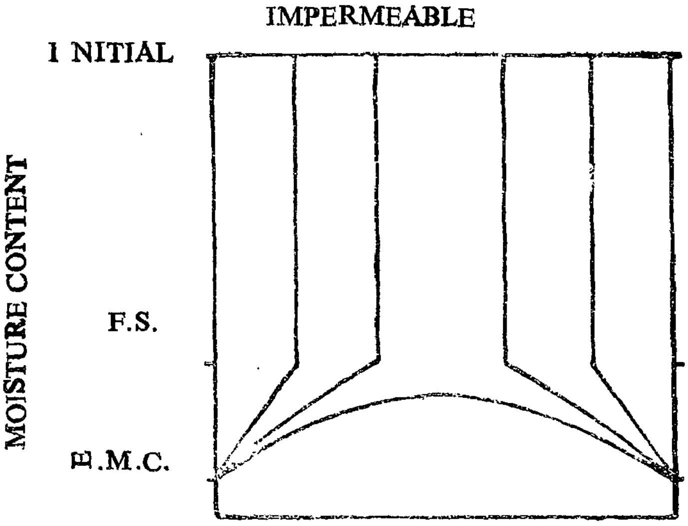
The permeability of wood to gases, vapours and liqids is of considerable importance in such diverse processing treatments is drying wood and paper, treating them with preservatives, fire retardents or dimension stabilizing chemicals and impregnating wood chips with pulping chemicals.

The term permeability is applied to the ease with which a porous medium enables fluid flow under hydro-dynamic conditions, i. e. under and applied total pressure gradient. The concept of permeability

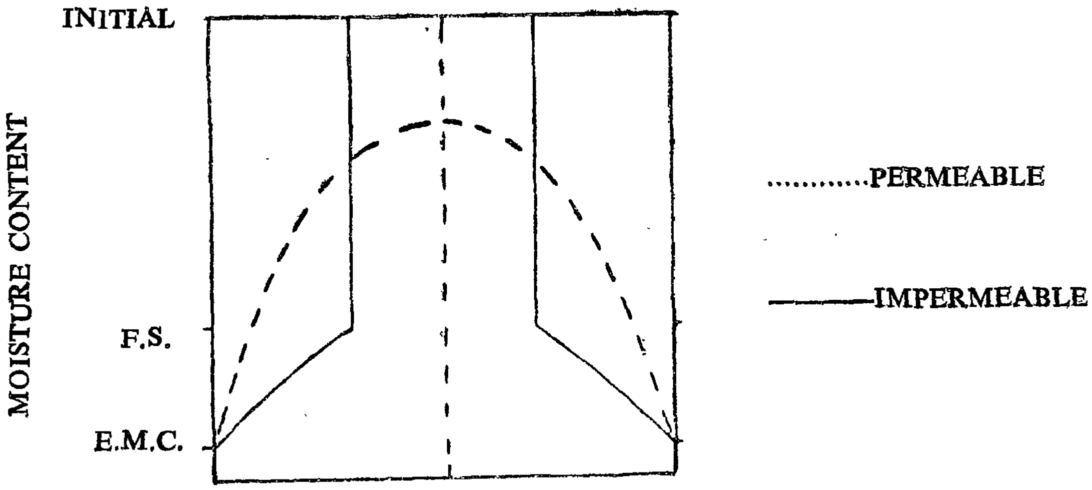
WOOD-WATER RELATIONSHIP



THICKNESS
Fig. XII—10 (a)



THICKNESS
Fig. XII—10 (b)



THICKNESS
Fig. XII—10 (c)

Effect of permeability on moisture gradients during drying.

differs from that of the diffusion coefficient which applies to the movement of a fluid under a partial pressure gradient co-existing with constant total pressure conditions. The permeability of a porous medium is a direct measure of the effective fractional cross section of continuous voids in the medium, which alone determines the ease of hydro-dynamic flow. In wood, it is considerably dependent upon the effectiveness of inter-connecting finer capillaries, such as the pit membrane pores, which constrict the passage-way from one cell cavity to the other. It may be mentioned that the minute passage-ways, through the pit membrane pores, serve quite efficiently to transport fluids under hydro-dynamic flow conditions but are much too small and scarce to provide for appreciable movement under diffusion conditions. This is because of the fact that not only the flow is proportional to the square of the effective flow cross-section under hydro-dynamic conditions and proportional only to the effective flow cross-section in diffusion, but the diffusion through such narrow pores is greatly hindered on account of the random movement of the molecules.

Extensive measurements have been recorded of the permeability of wood to air. The permeability shows little correlation with the variation of density or porosity between different species, obviously because the incidence of continuous voids rather than the total pore volume in the wood controls the permeability. Sapwood of a given species generally shows higher permeability than the heartwood, despite little difference between their densities, presumably because the inter-connecting capillaries between cell cavities in the sapwood are more open than in the heartwood. This is attributed to the generally higher content of extractives and incidence of "aspirated" pits in the heartwood.

The permeability of softwoods along the fibre direction may range from 50 to 100 times that across the fibre direction. This is due to the fact that the fibres are 50 to 100 times as long as they are wide, and therefore 50 to 100 times as many pits have to be traversed in series through the same thickness of sample in the across-the-fibre direction as in the fibre direction. In hardwoods, however, the ratio of longitudinal to transverse permeability varies more widely. This is on account of the variation in the structure and incidence of tylosis and extractives in the vessels between different hardwood species. Hardwoods like gurjan (*Dipterocarpur* spp.), in which the vessels are relatively open, enable air to be literally bubbled through in the fibre direction. Heavily tylosed species like gamari (*Gmelina aroborea*) and sal (*Shorea robusta*), on the other hand, are extremely impermeable in the longitudinal direction.

Measurements have also been recorded of the permeability of softwoods to air-water vapour mixtures at different equilibrium moisture contents below the fibre saturation point. The permeability was found to decrease gradually as the moisture content increased from the oven-dry condition to 20%. Thereafter it decreased very rapidly to zero, due to water condensing in the pit membrance pores. Beyond this stage, air flow could be continued only by applying quite high pressure to displace water from these pores by air.

Comparatively fewer measurements have been taken of the permeability of wood to water, because of the practical difficulties involved in such measurements. When the flow of water in green wood samples is measured under a constant pressured, the flow rate very frequently decreases considerably with time. Recently it has been demonstrated that the major part of this decrease in flow rate is due to dissolved air being released within the structure and blocking the free flow of liquid through the fine pit membrane openings. As the water is forced under pressure through these constrictions, a negative hydro-static pressure can develop, promoting release of the dissolved gas. Freshly boiled distilled water, passed through fine pore filters to remove particulate matter, reduces the blocking effect considerably. Passing the water through a densely packed cotton filter, prior to passing it through the wood, subjects the water to a large initial pressure drop, thus causing any remaining dissolved air to separate out in the filter rather than in the wood. By these means, a constant rate of flow of water through the wood has been attained.

REFERENCES

Anon.	1955	Wood Handbook No. 72; U.S. Deptt. of Agri., Forest Service; U.S. Govt. Printing Office.
Brown, H. P., Panshin, A. J. & Forsaith, C. C.	1952	Textbook of Wood Technology, Vol. II; McGraw-Hill Book Company, New York.
Gupta, H. K. & Rehman, M. A.	1957	Dimensional stability of timber, its significance in day to day use and suggestions for its determination by giving a new orientation. Paper sent for the 7th British Commonwealth Forestry Conference, Australia—New Zealand Aug., 1957.
Hart, C.A.	1965	The Drying of Wood; North Carolina Agricultural Extension Service, U.S.A.
I. S. I.	1960	Recommendations for maximum moisture content of timber used for different purposes in different climatic zones (Revised); IS : 287-1960; Indian Standards Institution, New Delhi.
Jaikishen, Ghosh, D. P. & Rehman, M. A.	1956	Studies in moisture content, shrinkage, swelling and intersection point of mature *Dendrocalamus strictus* (male bamboo); *Indian For. Rec.* (N.S.) 1 (2), Wood Seasoning; Manager of Publications, Delhi.
Kapur, S. N. & Rehman, M. A.	1936	Shrinkage studies on Indian woods, effect of high temperatures on the shrinkage and moisture equilibrium of wood; *Indian for Rec.* (N.S.) 1 (1), Utilization; Manager of Publications, Delhi.

Limaye, V. D.	1933	The physical and mechanical properties of woods grown in India; *Indian For. Rec.*, **18** (pt. 10); Manager of Publications, Delhi.
Narayanamurti, D.	1941	Variation of the electrical resistance of Indian timbers with moisture content *Indian For. Bull.* (N.S.), No. 105, Utilization Manager of Publications, Delhi.
Rehman, M. A.	1944	Survey of seasonal variation of the moisture content of Indian woods ; *Indian For. Rec.* (N.S.), **2** (10), Utilization; Manager of Publications, Delhi.
Rehman, M. A. & Gupta, H. K.	1961	Shrinkage studies on Indian timbers, Part I, *Tectona grandis* (teak) *Indian For. Rec.* (N. S.), **1** (3), Wood Seasoning Manager of Publications, Delhi.
Rehman, M. A., Jaikishen & Bali, B. I.	1956	Moisture content of wood and its determination *Indian For. Bull.* (N.S.), No. 213, Wood Seasoning; Manager of Publications, Delhi.
Sharma, S. N. & Bali, B. I.	1966	Some variable affecting the trend of unidirectional shrinkage along board width of toon (*Cedrela toona*) above the fibre saturation point in drying); *Indian For. Bull.* (N.S.), No. 252, Wood Seasoning; Manager of Publications, Delhi.
Sharma, S. N. & Madan, R. N.	In press	Preliminary experiments on the dimensional stabilization of some Indian hardwoods with Polyethylene Glycol—1000; *Indian For. Bull.* (N.S.), No. 260, Wood Seasoning; Manager of Publications, Delhi.
Stamm, A. J.	1964	Wood and Cellulose Science The Ronald Press Co., New York.
Tiemmann, H. D.	1944	Wood Technology; Pitman Publishing Corporation, New York.

CHAPTER XIII

DEFECTS IN TIMBER

General remarks

As timber is a natural products, it is seldom entirely free from features that tend to affect its strength, durability, colour, economic value, and grade. Any feature that only mars the appearance without affecting the technical quality of timber is called a *blemish.* Any feature that lowers the technical quality or commercial value and, therefore, the grade of timber is called a *defect.* Whether a particular feature is to be classified as a blemish or defect depends on the relevant grading rules or specifications, or the purpose for which the timber is intended. Thus a feature which may be considered only as a blemish in one context may amount to a defect in another. In this chapter, those features which are usually treated as defects are dealt with.

Defects may be classified under two broad heads : natural defects due to factors influencing the growing tissues in the living tree, and other defects that result from the activity of external agencies or the subsequent treatment of the felled timber. They are further classified and studied under sub-heads as shown below :

DEFECTS

- Natural
  - (i) Knots
  - (ii) Shakes (natural)
  - (iii) Cross grain
  - (iv) Reaction wood, etc.
- Other than natural
  - Caused during subsequent treatment of felled timber
    - Seasoning
      - (i) Warping
      - (ii) Checks, splits and shakes
      - (iii) Case-hardening, etc.
      - (iv) Collapse
    - Conversion and wood-working :
      - (i) Boxed heart
      - (ii) Imperfect grain, etc.
  - Resulting from activity of external agents
    - (i) Fungal defects
    - (ii) Insects and other animals

The methods of measurement and evaluation of the more common defects have already been dealt with in Chapter V—"Grading".

Natural Defects

These are abnormalities in wood which are due to the growth and environment of the living tree. These include (i) knots ; (ii) shakes (natural) ; (iii) cross grain ; (iv) reaction wood ; (v) compression failures ; (vi) resin pockets and resin streaks ; (vii) mineral streaks; (viii) bark pockets ; (ix) chemical stains; and (x) constriction due to climbers. Many of these are of limited occurrence, but some have appreciable effect on the mechanical and physical properties of wood. It is therefore necessary to discuss in some detail the more important natural

defects, so that these can be readily recognised and their effects allowed for in the utilization of wood.

Knots

Knots are the commonest type of defect. As the tree increases in diameter, it covers the bases of the lateral branches. The portions of the branches enclosed within the wood are called *knots*. If the branches are alive at the time of their inclusion, their tissues are continuous with those of the main stem, and the knots so formed are said to be *live knots* (or *intergrown knots*); these make *tight knots*. When a branch dies and a part of it is gradually covered by the live tissues of the wood, a *dead knot* (or *encased knot*) results; this is a *loose knot* and may fall out when the timber is converted.

Knots vary in size from a pin-head to several centimetres in diameter. They also vary in shape according to the angle at which they are cut during conversion. They have an important bearing on the utilization of timber and form the primary cause of degrade. They spoil the appearance and sometimes reduce the strength properties, besides giving rise to seasoning defects and difficulties in wood working.

Knots are classified as follows (IS : 707—1958 and B.C.F.T., Part II, 1957) :

(1) *Knots classified according to size*

(a) *Pin knot.*—A knot not more than 6.5 mm (or ¼″) in diameter.

(b) *Small knot.*—A knot more than 6.5 mm, but not more than 20 mm (or ¾″) in diameter.

(c) *Medium knot.*—A knot more than 20 mm, but not more than 40 mm (or 1½″) in diameter.

(d) *Large knot.*—A knot more than 40 mm in diameter.

(2) *Knots classified according to form*

(a) *Round knot.*—A knot oval or approximately circular in form, exposed in a section cut approximately at right angles of its axis.

(b) *Spike or splay knot* (Fig. XIII—1).—A knot sawn lengthwise, i.e. parallel to its axis and so having an elongated shape.

(3) *Knots classified according to condition*

(a) *Live knot* (Fig. XIII-2).—A knot free from decay and other defects, firmly intergrown with surrounding wood. Syn. *Intergrown knot ; Tight knot; Sound knot.*

(b) *Decayed knot.*—A knot softer than the surrounding wood and containing decay. Syn. *Unsound knot; Punk knot; Rotten knot.*

(c) *Loose knot.*—A knot which is not held firmly in place by growth or position.

(d) *Dead knot.*—A knot in which the wood elements are not completely intergrown with those of the surrounding wood. Syn. *Encased knot; Black knot.*

(e) *Pith.*—A sound knot with a pith hole not over ¼ inch (.6 cm) in diameter. Syn. *Hollow knot.*

(f) *Enclosed knot.*—A knot that does not appear on the surface of timber.

Two or more knots, so close together that the deflected wood fibres envelop the whole group, form a *knot cluster*. However, a group of single knots does not form a knot cluster.

A hole left as a result of the removal of a knot is called a *knot hole.*

The effect of live knots on bending strength depends upon their position. They seriously affect bending strength on tension faces, less seriously if on the compression side of the bent beam. They are of little consequence on direct compression or shear. In long columns, where stiffness is an important factor, they are of little significance.

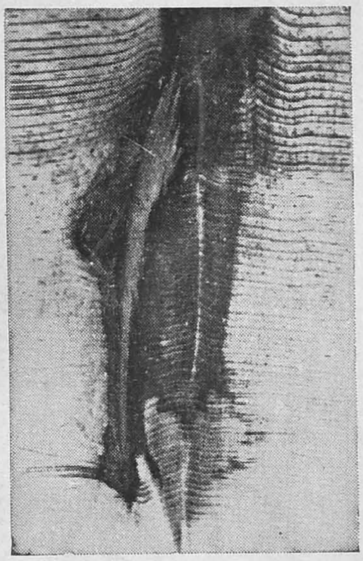


Fig. XIII—1. Spike (or splay) knot.

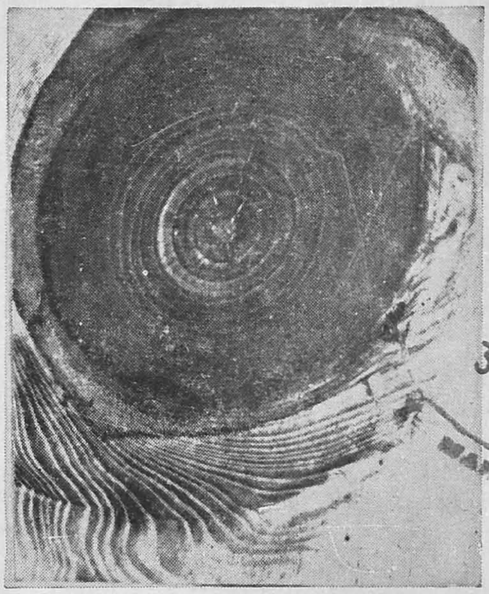


Fig. XIII—2. Live (or sound) knot.

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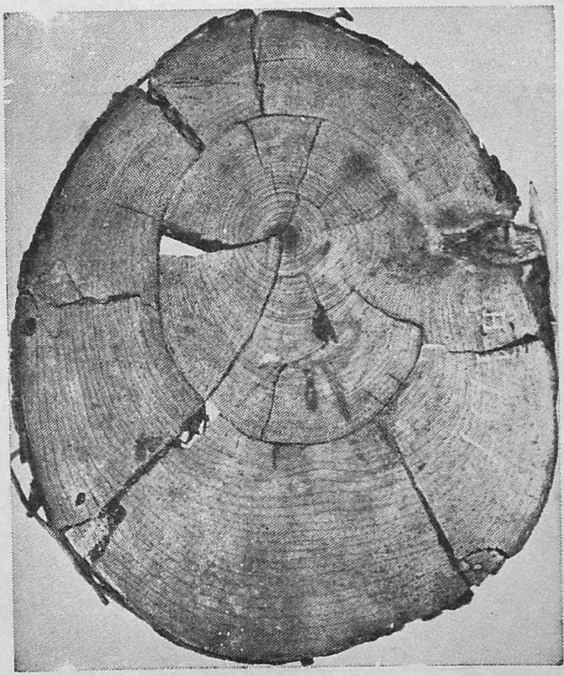

Fig. XIII—3. The end of a log showing various kinds of shakes.

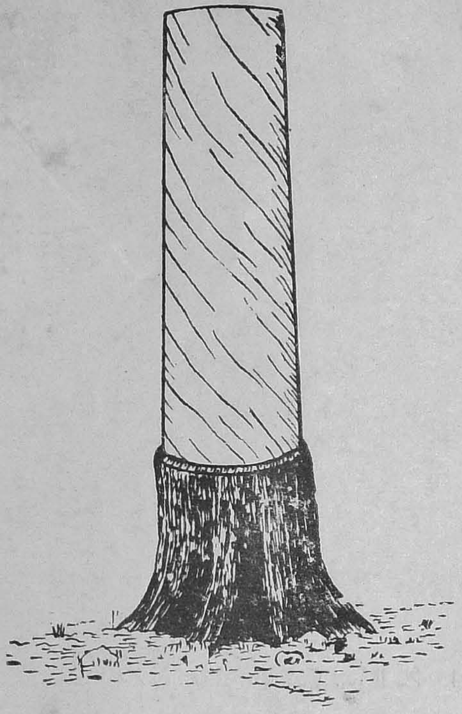

Fig. XIII—4. Base of a tree trunk with a portion of bark removed, showing spiral grain at the surface.

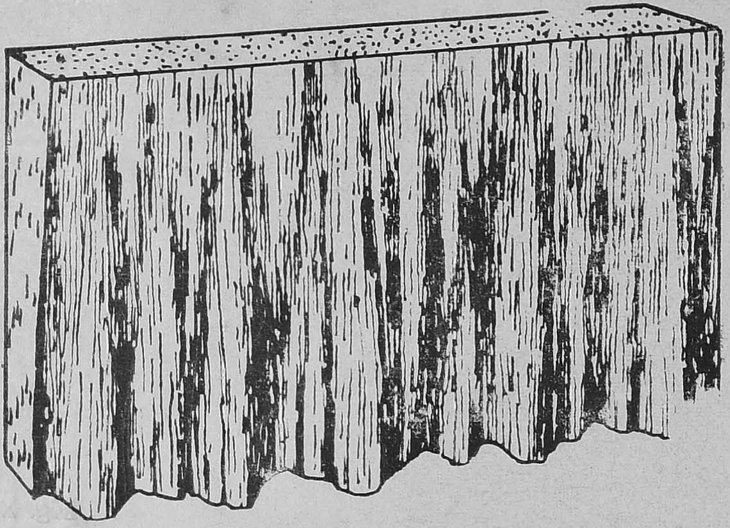

Fig. XIII—5. A block of interlocked grained wood, split radially.
(Adapted from "Text book of Wood Technology Vol. I" by Brown, Panshin and Forsaith).

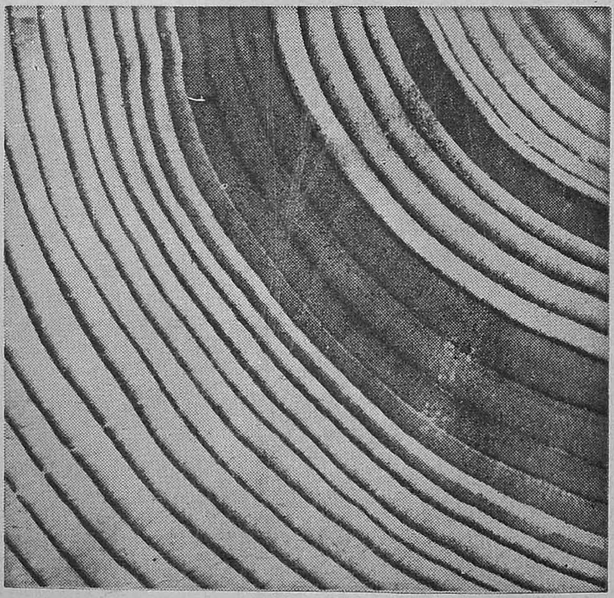

Fig. XIII—6. Cross section of a spruce log with conspicuous compression wood.

Shakes (*Natural*) (Fig. XIII-3)

A natural shake is a separation of fibres along the grain of standing or freshly felled timber, forming a crack or fissure that is generally confined to the interior of the timber but sometimes extends to one surface. It is generally caused by stresses in the interior of the tree, as a result either of growth or climatic conditions, especially wind, or of felling. The term is usually applied to timbey in the log or of large size. When the crack or fissure extends through the piece from one surface to another, it is called a *split* or, sometimes, a *through-shake*.

When a tree is swaying in high wind, different stresses are set up inside it, tension on the windward and compression on the leeward side. If the tree is sufficiently elastic, it takes up the strain without suffering any internal injury; on the other hand, the pressure may be so great that there is a separation of tissues inside the trunk. If the separation takes place along the annual rings (between the dense summer grown wood and the open-celled growth of the succeeding spring), *ring shake* or *cup shake* develops. The former term is applied to a shake which follows the complete circuit of the annual ring, while the latter is used when the shake is restricted to a portion of the ring only. Chir (*Pinus roxburghii*) and oak (*Quercus* spp.) are prone to cup shakes. These cannot be prevented, but their extension to sound timber can be prevented by slow seasoning. Cup shakes sometimes occur due to severe frost; they arise in such rings which constitute a zone of weakness.

A second zone of weakness occurs along the sides of the rays. Hence we find a second type of cleavage running radially across the centre of the log. This is called *heart shake*, or if there are more than one shake radiating from the centre, the resulting shake is described as a *star shake*. Shakes of this nature originating during growth may be extended farther in the process of felling, conversion or seasoning. Any shake caused by felling is known as a *felling shake*.

Evidence of development of shakes and splits during growth is provided by secretions of resin or slight discoloration in the wood.

Cross grain

This is general term denoting the deviation of the wood fibres from a direction parallel to the longitudinal axis of the tree. It may be present only in restricted areas of the wood. It may be due to interlocked fibre, uneven growth of annual rings or intersection of branch and stem. Cross grain is expressed as a slope, e.g. 1 in 15, meaning that the grain is 1 cm. away from the axis over a distance of 15 cm. Sub-types include diagonal, spiral, interlocked, wavy and curly grains, of these only the first two or normaly considered as important defects in structural timbers.

Diagonal grain (Syn. *Oblique grain; Sloping grain*).—It refers to the occurrence of fibres at an angle to the longitudinal surface of a piece of timber due to faulty conversion of otherwise straight-grained timber, and is thus not a natural defect. Timber with diagonal grain is weaker than that properly swan.

Spiral grain (Syn. *Twisted grain*).—Fig. XIII-4 denotes an arrangement of the fibres helix round the axis of the bole or branch of a tree. This is a common defect in many timbers and, when excessive, greatly reduces their structural strength. This is well illustrated in the 'twisted' chir in Uttar Pradesh, where in the Almora district many chir forests contain, almost entirely, trees with bad spiral growth. This renders the wood absolutely useless as timber. Such wood was used in the past only for firewood charcoal, and chir-tar by distillation, but is lately being utilized for pulping. Twisted chir trees are, however, suitable for resin-tapping and are put to this use.

Interlocked grain (Syn. *Interwoven grain*).—Fig. XIII-5 shows this type of grain in which the angle of the fibres changes or reverses periodically in successive layers. *Wavy grain* is produced by an arrangement of the fibres in short, fairly uniform waves or ripples. This is usually not considered a defect except where strength and fissility are concerned. On the other hand, wavy grain is sought after for furniture. *Curly grain* is due to fibres forming irregular curves or undulations. *Burrs* are irregular masses of wood with excessive waviness; these, though technically defects in wood, in practice may be of far greater value than the rest of the tree owing to their exceptionally fine figure,

Reaction wood

Wood with more or less distinctive anatomical characteristics, formed typically in parts of leaning trees and in branches, is designated as *reaction wood*. In conifers this abnormal wood is found on the underside of branches and leaning trunks, and is called *compression wood* (Fig. XIII-6). It is characterised anatomically by rounded, heavily lignified tracheids. Zones of compression wood are typically denser and darker than the surrounding tissues. The outstanding feature of compression wood is its abnormally high longitudinal shrinkage. Whereas normal wood shrinks 0.1 to 0.2 per cent from the green to the oven-dry condition, compression wood may shrink from 0.3 to as much as about 6 per cent. In consequence, boards and planks containing compression wood are liable to bow in seasoning. Though denser, compression wood has low bending strength and lacks toughness. In hardwoods, abnormal wood forms generally on the upper side of leaning trunks and branches and is known as *tension wood*. Tension wood is characterised anatomically by little or no lignification. It is generally associated with eccentricity of growth, with the wider growth rings on the tension side. It has an abnormally high longitudinal shrinkage, tending to warp and cause splitting, and the machined surface tends to be fibrous or woolly, especially when green.

Compression failures

These comprise localised buckling of the fibres caused by compression, either by end- compression or in bending. Natural compression failures develop in standing trees due to internal stresses set up by rain, snow, unequal growth, etc. They appear as minute fractures running across the grain, the fibres being crinkled by compression or broken transversely, and are often very difficult to detect until the timber is surfaced.

Resin pockets and Resin streaks

A number of defects, known as resin pockets and resin streaks, may occur in softwoods which normally possess resin canals. These defects develop as a result of excessive accumulation of resin so that resin-soaked patches or pockets are found in the wood. Similar defects also occur in one hardwood family, Dipterocarpaceae. In this family, the defects are usually smaller than those found typically in softwoods. Also, their cell contents consist of solidified dammars or oleo-resins. A well-defined intercellular cavity in timber, more or less lens-shaped and containing resin, is called *resin pocket* (or *pitch pocket*). Resin pockets range from 0.3 cm to several centimetres in width circumferentially, up to 2.5 cm in depth radially, and up to 30 cm in length. The terms *dammar pocketr*, *gum duct* and *gum pocket* refer to similar cavities or canals containing resinous or gummy matter in certain timbers. A local accumulation of resin in the form of a streak, occurring in certain softwoods, is called a *resin streak*. Resin streaks do not influence the strength in any way.

Mineral streak

Mineral streak is defined as a localised discoloration of timber in the form of streaks or patches usually darker than the natural colour. This does not impair the strength of the wood. It is found in certein hardwoods.

Bark pockets (Syn. *Occluded bark*)

Pockets of bark are sometimes included n the wood of the main stem. They arise from the bark in a flute, or that associated with a knot which has been partially or wholly enclosed by the subsequent growth of the tree. Resin or gum may sometimes be present in the pocket. Bark pockets constitute a defect, the seriousness of which depends upon the size of the pocket, its location, and the extent to which decay may have crept in.

Chemical stains

These are caused as a result of chemical reaction between a constituent of the wood and some extraneous substance. Brown stain develops generally in the heartwood, and is apparently caused by the oxidation of extractives.

Constriction aue to climbers

Climbing plants can do considerable damage to trees by so contorting the stem as to make its shape practically useless for commercial purposes. This is caused by the climber growing spirally round a

small tree in the first place. In the course of years, the climber grows thicker and stiffer, while the stem round which it has would itself is also growing. The result is that the climber is unable to loosen itself from the tree, and as the latter expands in girth the climber presses so tightly against it that it is eventually grown over by the expanding tree and finally gets embedded in the stem; the bole has then a deep spiral groove running from the bottom to the top. Among the most common climbers which attack forest trees in this way are *Bauhinia vahlii* and *Butea parviflora* (Syn. *Spatholobus roxburghii*).

Some climbing plants start from seeds dropped by birds in crevices and branch cavities on mature trees. These germinate and throw out roots which grow downward over the stem unntil they reach the ground. They then increase rapidly in size, often enveloping the host plant and eventually killing it. Examples of this type of pest are *Ficus bengalensis* and *F. religiosa.* There is yet onther type of climbing plants which climb by means of tendrils or priceles or e. g., *Rosa moschata, Acacia pennata.* Such climbers do not damage the wood of the trees, but they do affect their shape and development.

Seasoning Defects

Next in importance only to defects caused by knots are those caused by faulty seasoning technique. As already explained in Chapter XII, Wood shrink as it dries, and the rate of shrinkage varies in the three principal directions. Moreover, the outer layers of a piece of wood tend to dry out more speedily than the interior, resulting in permanent or temporary distrortion in the timber, and even in the separation or rupture of tissues. The different types of permanent distortion of timber and ruptures of tissues constitutes; separately or together they are referred to as *degrade in seasoning* or *seasoning degrade.* Distortion gives rise to various type of *warping,* while rupture of tissues *checks, splits* and *shakes.* The prinicipal types of seasoning defects are described below.

Warping (Syn. *Buckling)*

Warping refers to distortion in converted timber, causing departure from its original planes, usually developed during, seasoning. The main forms of warping are *bowing, cupping, spring,* and *twist* (Fig. XIII-7). These are explained below.

In *bowing,* the face becomes concave or convex *along* the grain. It is caused by too tide a spacing of stickers, which causes the timber to sag under its own weight.

In *cupping,* the face becomes concave or convex *across* the grain. In flat-sawn material, one surface is more nearly radial than the other and, since radial shrinkage is less than the tangential, the face toward the pith tends to shrink less than the opposit face; hence the board becomes cupped when dry. Cupping can be reduced by proper stacking. Cupping does not occur in truly quarter-sawn timber.

Spring is a distortion in the longitudinal plane, the board or plank remaining flat. If it is laid on its tangential edge, it forms a flat arch.

Twist is the spiral or cork-screw distortion of a board along the grain. In extreme cases, the timber may be renderted useless. Twisting is often caused by spiral or interlocked grain, but it may also be brought about by unequal shrinkage caused by variation in density within the board. It can be minimised by weighting the stacks with heavy baulks immediately after the stacking is done and before drying has commenced.

Checks Splits and Shakes (Fig. XIII-8)

Checks, splits and shakes are all instances of the separation or rupture of the the wood along the grain, i.e., in the longitudinal plane, and should be distinguished from horizontal fractures that arise from causes other than drying stresses. Between themselves the three forms differ in whether the crack or fissure is confined to the interior of the wood, or extends to one surface or from one surface to another.

In a *check,* there is a separation of fibres, which forms a crack or fissure *not* extending through the piece from one face to othere. The term is usually applied only to converted timber.

In a *split,* the crack extends from face to face. An end-split is one that occurs at the end of a log or piece of timber.

The term *shake* has already been explained and its different forms mentioned under 'Natural Defect'. It is is usually applied only with reference to timber of large size or in the form of logs. Shakes

may originate as a result of seasoning stresses. Apart from ring shakes, heart shakes and star shakes, which have been earlier referred to, converted timber is liable to *round shakes*—which are ring shakes completely encircling the heart—and *shell shakes*—in which parts of ring shakes show on the face or edge of converted timber. Converted timber affected by shell shakes is described as *shelly.*

Case-hardening, Reverse-case-hardening and Honey-combing

In a piece of green wood the surface layers usually dry before the interior, and tend to shrink, but they are prevented from doing so by the wet inside portion. This results in tension across the grain in the surface layers, and a corresponding compression in the interior. The condition of the timber in which surface layers become set in a stretched condition (in tension) and the interior under compression is known as *case-hardening.* Case hardened timber is liable to cupping, warping and other forms of distortions during planing and resawing.

Case-hardening can be removed by subjecting the timber to a conditioning treatment (sometimes incorrectly called "steaming"), at a temperature of 70°C or above and at relative humidities sufficient to balance the moisture content between the core and the shell. Under such treatment the wood becomes sufficiently plastic to yield to the stresses, thereby freeing the timber from case-hardening.

If the case-hardened timber is further seasoned, resulting in the drying of interior layers of wood, the interior tries to shrink but it is prevented by the outer layers which are already set in tension. This causes tension in the interior layers and compression in the outer layers. If the tension stresses in the interior exceed a certain limit, internal cracking known as *honey-combing* results, just as excessive tension in the surface layers causes surface cracks.

In honey-combed wood the internal checks usually run along the wood rays (Fig. XIII-9). They are not visible at the surface and therefore cannot be detected before the timber is fashioned.

Sometimes a condition known as *reverse-case-hardening* may occur in wood, if case-hardened, timber gets over-steamed in an attempt to relieve case-hardening. In this case the outside layers are permanently set in compression.

Collapse

Collapse is a defect which develops in certain species when very wet heartwood is dried. The usual indications are abnormal and irregular shrinkage. The affected timber assumes a wrinkled or corrugated appearance (Fig. XIII-10).

Collapse differs from normal shrinkage in that the cell walls may be actually pulled together, and the cells collapsing in the extreme case. Collapse is more common in kiln drying as the wood becomes soft and plastic to a certain extent at high temperatures. Collapsed timber can be restored to its orginal size by steaming at 100° C for about 4 hours in case of 2.5 cm thick planks.

Eucalypts are particularly susceptible to collapse. Out of Indian timbers, toon (*Cedrela toona*) and chilauni (*Schima wallichii*) have been found to be liable to collapse during kiln seasoning.

Defects due to Conversion and Wood-working

Timbers may sometimes contain defects due to faulty conversion or machining. Such defects are briefly described below :

(1) *Boxed-heart.*—This term is applied to timber so sawn or hewn that the pith or the centre-heart falls entirely within the four surfaces throughout its length. It is considered as a defect in some pecifications.

(2) *Imperfect manufacture.*—This is a term used in a general way to include all defects associated with timber conversion and wood-working. It covers all the individual defects described under S. Nos. 3 to 9 below.

(3) *Imperfect grain.*—This is a general term which may include one or more of the following defects :

(i) *Chipped grain.*—This is a machine defect of surfaced timber caused by the breaking or tearing away of wood below the finished surface by the action of a tool or a cutter.

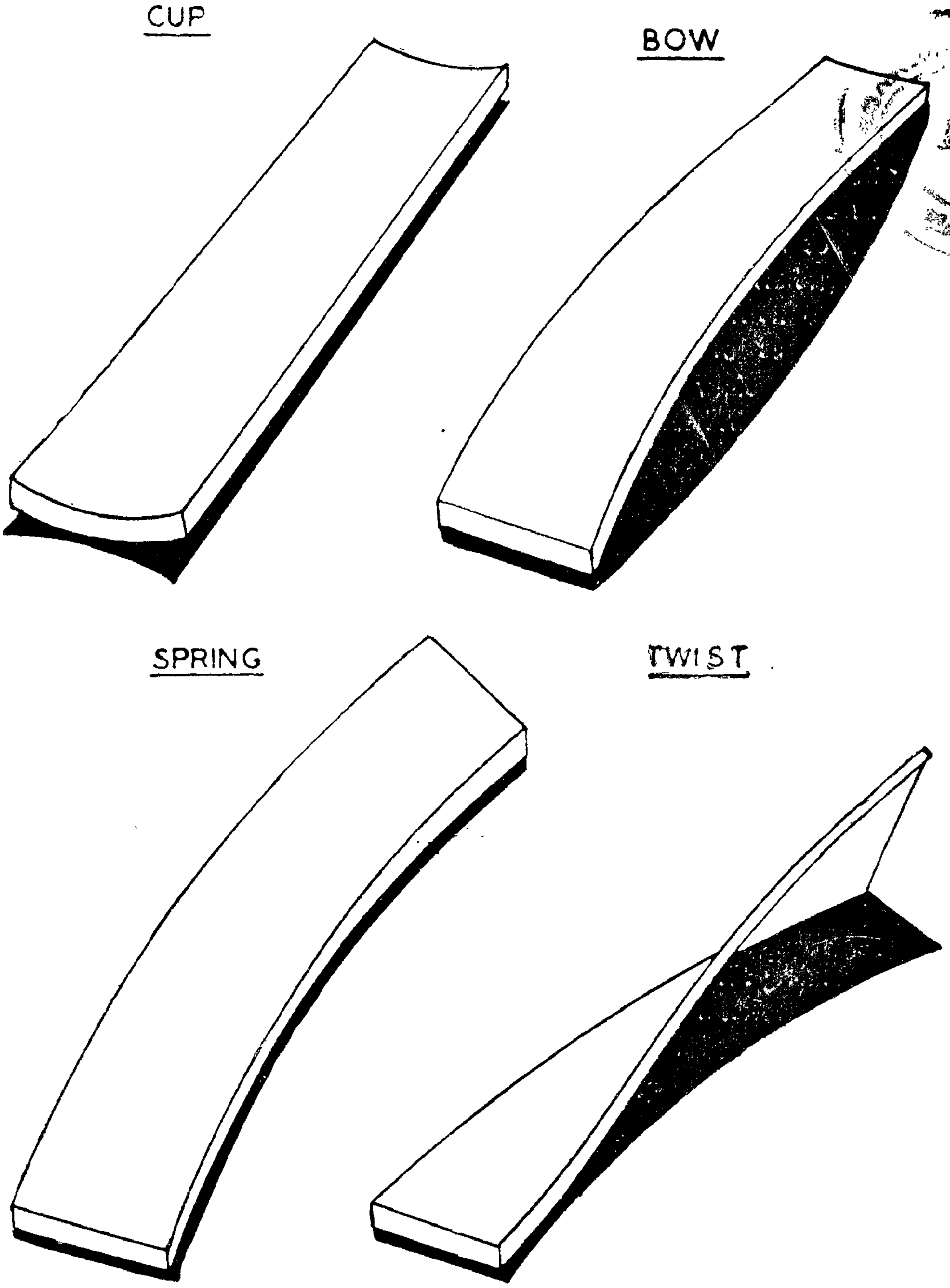

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Fig. XIII—7. Warping defects.

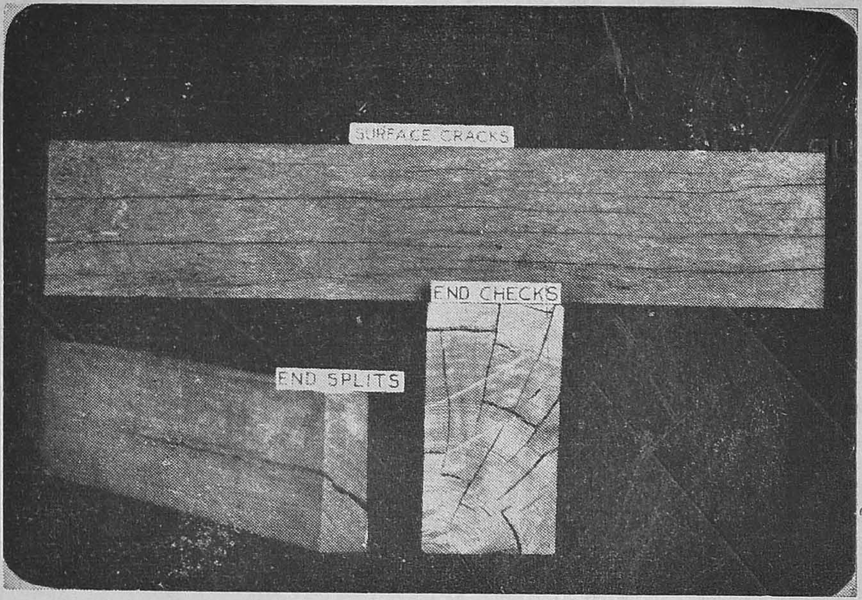

Fig. XVIII—8. Surface cracks, end splits and end checks.

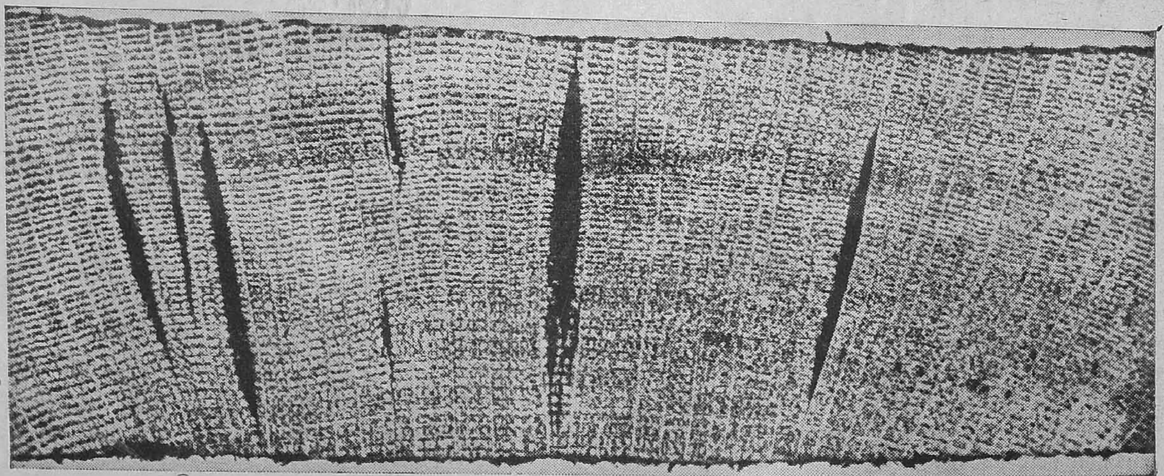

Fig. XIII—9. A piece of oak timber showing internal cracks or honey-combing.

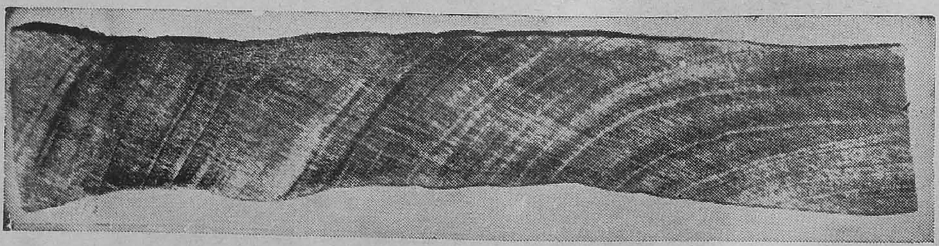

Fig. XIII—10. Collapse in a toon plank.

(ii) *Diagonal grain* (Syn. *Oblique grain* ; *Sloping grain*).—It refers to the occurrence, due to faulty conversion, of fibres at an angle to the longitudinal surface of a piece of timber. It often arises from the practice of sawing logs parallel to the pith rather than to the bark. It may some-times be due to a natural crook in the tree. In the trade, both spiral and diagonal grain are called "cross grain". Diagonal grain is quite a serious defect in as much as it reduces the strength of timber and increases its liability to check, warp and twist.

This defect can be avoided, or at any rate minimised, by careful sawing.

(iii) *Raised grain.*—This is a defect, due primarily to the use of blunt cutters, consisting of a roughened condition of the dressed surface of timber; some portions of the dense late wood are raised above the less dense early wood but are not torn loose from it. The surface of the board with raised grain has a corrugated feel and appearance. The type of raised grain in which the edges and tips of the annual rings get loosened and curled is known as *loosened grain*, and is dealt with below.

(iv) *Loosened grain.*—This defect on a flat sawn surface is caused by the separation or raising of wood fibres along the growth rings. A small portion of the wood becomes loosened but not displaced. It is caused by excessive pressure exerted in planing or sanding, sufficient to crush the spring wood under a layer of summerwood exposed on the face of a board, and subsequent shrinkage stresses that develop in the wood.

Timber with loosened grain is difficult to machine and paint.

(v) *Torn grain.*—It is a machine defect caused by the tearing of wood fibres below the finished surface by the action of a tool or cutter. It is generally classified as slight, medium, heavy or deep, depending on variation ranging from 0.8 mm (1/32") to 3.2 mm (1/8").

(4) *Machine burn.*—It is evidenced by the dark charred patches on machined wood and is due to over heating of the machine cutters.

(5) *Machine notches.*—This defect manifests itself in the form of grooves, recesses or trenches occurring on the surfaces of machined timber due to excessive chipping.

(6) *Machine gauge.*—It is a groove across a piece of fashioned timber due to the machine's cutting below the desired line of cut.

(7) *Miscut timber.*—The timber which is not cut straight or correct to the dimensions as required, or shows a variation greater than is permissible, is called *miscut timber.*

(8) *Mismatching.*—An imperfect alignment or fit at a joint of two adjoining pieces of matched planks due to faulty machining is known as *mismatching* or *imperfect dressing.* This is classified as slight, medium or heavy depending upon the surface variations ranging from 0.4 mm (1/64") to 0.8 mm (1/32").

(9) *Skip.*—In planing operation, slight depressions that may occur below the line of cut in the boards are missed and remain in rough unplaned condition; these are known as skips (Syn. *Skip-in planing*; *Skip-in-surfacing*). A series of skips is sometimes referred to as "hit and miss".

(10) *Wane or waney edge.*—This term is applied to indicate presence of the original sapwood surface, with or without bark, on any face or edge of sawn timber. This defect denotes lack of wood on the waney edge.

Fungal Defects in Timber

Stain and decay

As an organic material, wood forms a suitable food-base for fungi which, unlike green plants cannot synthesise food from inorganic sources due to lack of chlorophyll and so need organic food for their growth.

The two principal defects in the wood due to fungal attack are *stain* and *decay.* Fungi causing stain in wood feed only on food materials stored in the sapwood to which they are confined, and do not attack the heartwood which normally does not contain food stored within the cell. The presence

in the heartwood of substances toxic to fungi, at least in the durable species, may also explain the freedom of heartwood from strain. Stain is, therefore, referred to as sapstain and also blue stain, since the affected wood is usually turned blue, though wood may occasionally take a different coloration. Fungi that cause stain in wood belong to Fungi Imperfecti and also *Ceratocystis* spp. (Ascomycetes). The spread mostly by spores embedded in mucilage. As such, they are disseminated by insects, particularly bark beetles, which may infest dying trees or logs. The spores are also disseminated by wind, and this process is largely responsible for stain in freshly-sawn wood.

A decay fungus, also termed wood-destroying or wood-rotting fungus, on the other hand, draws its nourishment from the cell-wall material, which it breaks down by enzymatic activity. It may cause decay in both sapwood and heartwood. Decay fungi mostly belong to Hymenomycetes (Basidiomycetes). They usually develop large fruiting bodies (also termed sporophores or fructifications on the surface of wind. Large quantities of spores are liberated from these fruit bodies and are dispersed by wood. When they fall on a suitable substrate, they germinate under proper conditions of temperature and moisture and cause infection. Fruit bodies of decay fungi develop regularly and often appear many years after infestation of the tree or timber.

Origin of decay and stain

In the standing tree, either the heartwood or the sapwood may be attacked by wood-destroying fungi. When such decayed trees are converted, the decay is also passed along to the converted wood. Since heartwood forms the major portion of commercial timber on account of its durability and strength, decay in the heartwood is of great economic significance.

While the heart-rot fungi seem to persist indefinitely in living trees, they vary in their ability to continue development in the wood after conversion of diseased trees. Fungi which attack standing trees may not continue to disintegrate wood in service, so that wood with incipient decay has been successfully used to a large extent in sleepers, poles and buildings. When such rot occurs in converted wood, the term 'inactive rot' may be applied to it. In other cases, the fungi which occur in the living trees may remain active even after conversion of the decayed tree and continue to cause decay to the wood in the service. However, unless it is definitely khow that a fungus will not cause decay in wood that is in service, it is inadvisable to use timbers with incipient decay where durability and strength are important.

On the other hand, when a healthy tree is converted, the wood is originally sound but may subsequently become decayed during service. In such cases, the decay occurs 'de novo' in the converted wood.

Fungal stain does not normally occur in standing trees because of the high moisture content in the sapwood. After coversion, the stain appears in freshly-sawn timbers due to the lowering of moisture content in the wood. While decay is important in all timbers, stain is important in species containing a large amount of sapwood and in soft hardwoods used in the pulp, match aircraft and sports goods industries.

Factors causing wood decay

The decay fungi usually develop in wood in the form of mycelium, which consists of branched filaments called *hyphae*. Inside the wood the fungus passes from cell to cell, consuming food material during the process. The fungi require an optimum concentration of air and moisture in the wood for their growth. Air (oxygen is necessary for fungi to respire. Insufficient air may act as a limiting factor, and if air is removed by saturation of the wood with water the fungi die. The moisture content in wood, at which optimum fungus growth occurs and also at which the growth is inhibited, may vary with species. Fungi cannot grow in the wood if the moisture is approximately below 20 per cent as based on oven-dry weight of wood. If however, the infected wood is air-dried, the fungus may not die, at any rate early, but its active growth ceases. The fungus may remain dormant for serveral years in this condition. Several workers have shown that fungi can service for long periods, as much as 9 years, in air dry wood. If such wood is moistened, the fungus may revive and continue its growth in the wood. With increasing specific gravity of wood, the upper limit of moisture content in the wood at which decay is inhibited decreases. This is explained by the fact that with increasing specific

gravity, there is more wood substance in a given volume of wood, so that it will require less moisture to limit the air supply to a point below which the fungus will not grow. As regards temperature, wood-destroying fungi can develop over a fairly wide range, about 16°—32°C. Their activity decreases at temperatures above and below this range. At temperatures as low as near the freezing point, and as high as about 43°C, the fungi cease to grow in the wood.

Nutrition of decay fungi and types of decay

The mycelium of the decay fungus in the wood attacks the cell wall and obtains nutrition from it. In this process, the hyphae exclude various enzymes into their substrate and thereby convert the chemically complex wall material into simpler water-soluble products, which are further acted upon by endoenzymes in the course of fungus metabolism. These enzymes are selective in action. The ability of fungi to attack various components of wood is determined by the types of enzymes they secrete. In fungi causing brown rots, the dominant exoenzymes are hydrolytic, and attack principally cellulose and very little, if at all, the lignin. Such wood, after decay, appears more brown than normal wood due to the greater precentage of lignin in it. The decayed wood also cracks in all directions into cuboidal blocks (Fig. XIII-11), which easily become powdery if pressed with the thumb. When such decay occurs in structural timbers, as in buildings, the term 'dry rot' is applicable. The term 'dry rot' is a misnomer since such a rot, as well as others, occurs only under damp conditions.

In fungi causing white rot, the primary decomposition of wood involves a combination of oxidation and hydrolysis. Oxidising exoenzymes are necessary for the breakdown of lignin. These fungi, therefore, attack all constituents of wood, including lignin and cellulose. Due to loss of lignin, which imparts brown colour to wood, the decayed wood becomes white and the rot is known as *white rot*. The white rot may be fibrous in appearance (white fibrous rot), or the decayed tissues are delimited in pockets separated by more firm wood (white pocket rot) (Fig. XIII-12).

Characteristics and effects of decay

Various stages of decay are recognised. In the early or incipient stage, the wood has a normal appearance, although in a few cases there may be a change in colour. This stage, which can be detected by microscopic or cultural diagnosis, may be easily overlooked, and so, if the wood is put to use, under favourable conditions the decay may continue to progress and eventually lead to the structural failure of the timber. Incipient decay is, therefore, dangerous. From this stage onward, the wood becomes noticeably affected until it is finally changed completely in structure and appearance in the advanced stage of decay.

Change in the colour of wood is not always a sign of incipient decay, as such change of colour may be due to other causes. Some decays are associated with the formation of dark brown to black zone lines, and emit characteristic odours. In incipient decay the wood may not necessarily be weakened, particularly in white rots, though brown rots usually impair the strength to a considerable degree. In the advanced stage of decay, all mechanical properties of wood are seriously affected and such wood is useless for any purpose where strength is required. While the yield of unbleached pulp from healthy and stained bamboos is the same, that obtained from decayed bamboo is low. Again, sheets made from decayed bamboo pulp have appreciably lower strength than those from stained bamboo pulp. Healthy bamboo pulp sheets have higher strength than sheets from stained bamboo pulp. Decay results in the lowering of the specific gravity of wood, so that the amount of wood substance per unit volume decreases. Decayed wood has thus less calorific value, on volume basis, and yields low-grade fuel.

The microscopic characters of decay include the presence of hyphae in the cells. The hyphae pass from cell to cell, the penetration occurring probably by chemical action, and this results in bore-holes in the wall. In utilizing the cell-wall material as food, the hyphae cause corrosion marks, uneven thickness of the secondary walls leading to their disintegration, enlargement of pits, and dissolution of bordered pits. The damage in the cell wall mainly accounts for reduced strength of decayed wood.

Sapstain

As stated earlier, sapstain fungi feed on food stored in the sapwood and, unlike decay fungi, do not attack the cell wall. Except for this difference in the mode of nutrition, sapstain is influenced by factors like air, moisture and temperature in generally the same way as decay fungi.

Since the staining fungi do not attack the cell wall, most of the strength properties of wood, except toughness, are not affected. Stained wood can thus be used for purposes where similar but unstained wood is recommended, except where toughness is required. However, because of the discoloration it causes, sapstain is not liked by timber users where colour is of primary consideration, as in match-sticks, furniture, bobbins, packing-boxes, etc. Stained wood, after it has been seasoned, is much more permeable than healthy wood to penetration of liquids. In the use of sapwood in out-door locations, where its treatment with wood preservatives is necessary, stain may therefore be advantageous. If, however, heavily stained wood is used for paper manufacture, the pulp becomes stained and the cost of bleaching is increased.

Diagnosis of decay and stain

Incipient decay can be detected by the change in the colour of wood in some cases, from the microscopic characters of the decayed wood, and also by isolating the causal fungus in culture. Advanced decay presents definite patterns in respect of 'white' and 'brown' rots as stated earlier. In the former, the decayed wood comes off in splinters when rased with a knife point. In the latter, the decayed wood becomes powdery under the pressure of fingers. The fungus can be isolated in artificial culture only if it is alive, the isolation helps in determining whether the decay is active or not. Identification of decay fungus in culture, in the absence of any associated fruit body, is possible by studying the cultural characters and by comparing them with those of cultures isolated from fruit bodies.

Soft rot

In addition to the white and brown rots, a third type of decay in wood, namely, soft rot, has come to be recognised of late. Fungi causing soft rot are different from those causing white and brown rots.

Soft rot is usually limited to a depth of a few millimetres from the surface, and thus can be scraped off to reveal sound wood beneath. Soft rot is recognised by the brittle fracture of the affected wood when broken across the grain. Soft rot fungi have their optimum growth in acid media (pH 6-7) and some grow well in alkaline substrate (pH 7-8), at which the growth of most decay fungi is inhibited. Soft rot fungi attack mainly cellulose, and the hyphae are mostly confined to the secondary wall in which the dissolution occurs in the form of pits or cavities. The hyphae take a spiral course within the secondary wall.

Since soft rot is usually confined to surface layers of wood, it may be of consequence mainly in thin sections of wood, like plywood, under situations favourable for infection. Besides being present on posts, etc., soft rot also occurs in wood with high moisture as in slats on cooling towers, where other decay fungi are mostly inactive (Fig. XIII-13).

FUNGAL DEFECTS IN WOOD

- SAPSTAIN — Fungi feed on cell contents ; most strength Properties of wood are unaffected, e.g., *Ceratocystis*.
- DECAY — Fungi attack cell wall for nutrition, thus affecting strength properties of wood.
  - WHITE ROT (All components of cell-wall material attacked)
    - SPONGY ROT e.g., *Polyporus hirsutus*
    - POCKET ROT e.g., *Polyporus abietinus*
  - BROWN ROT (Cellulose attacked, lignin unaffected)
    - In timber other than house timber
      - BROWN CUBOIDAL ROT e.g., *Lenzites sepiaria*
    - In building timber
      - DRY ROT e.g., *Merulius lacrymans*
      - WET ROT e.g., *Coniophora cerebella*
  - SOFT ROT (Cellulose in secondary walls attacked; causes brittle fracture in wood) Occurs in wet situations, e.g., cooling towers and timbers used in sea-water.

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Fig XIII—11. Brown cuboidal rot on a creosote surface treated sal pole.

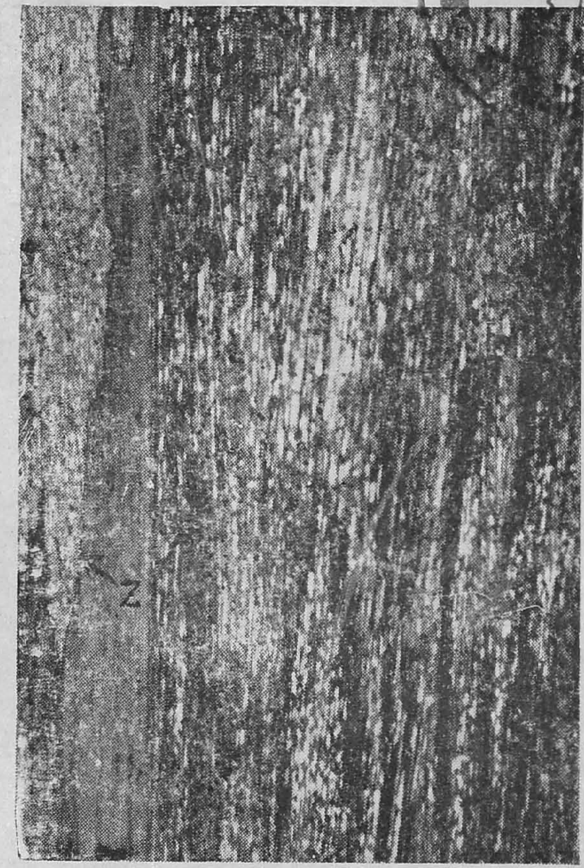
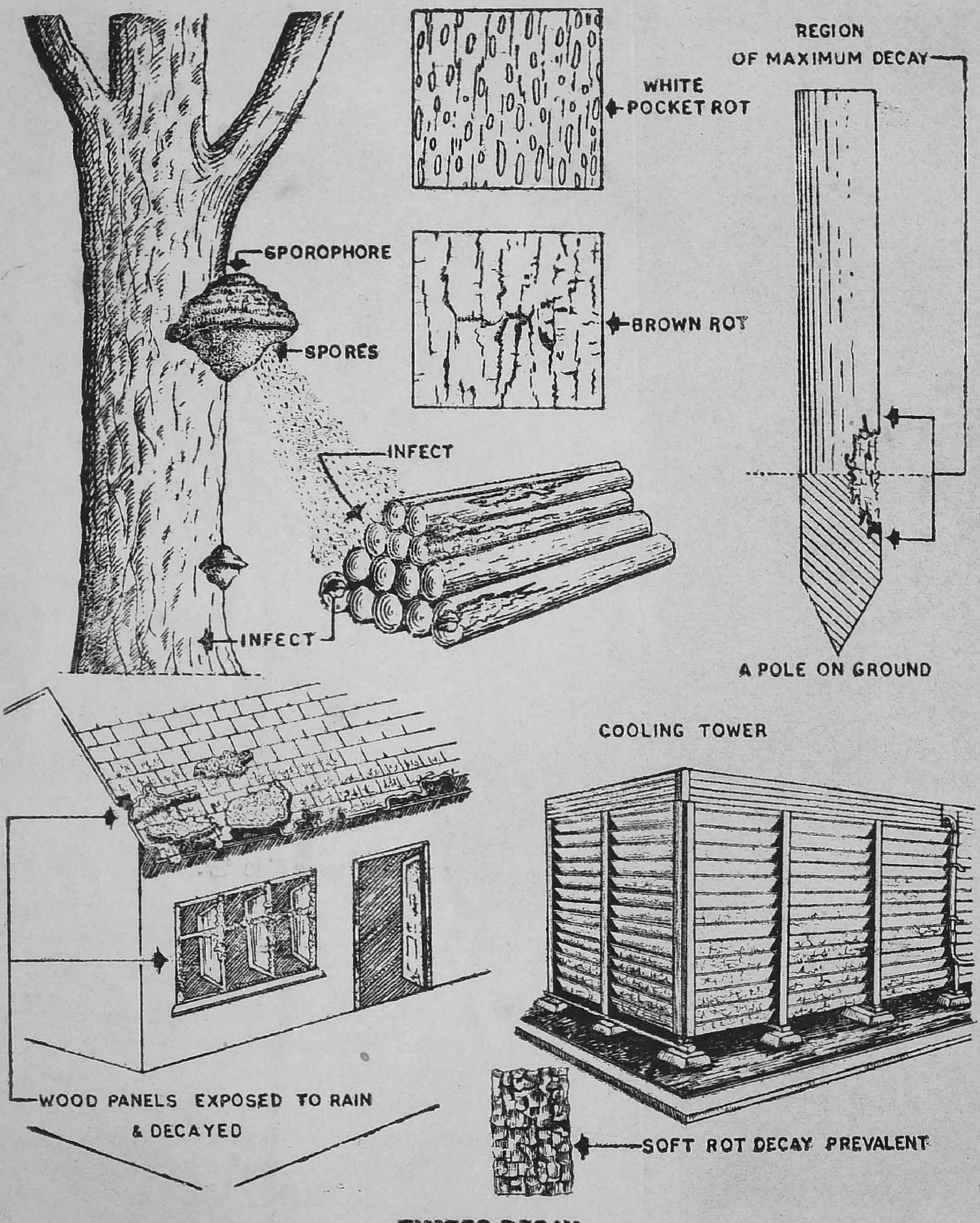


Fig. XIII—12. White pocket rot in wood showing zone line 'Z'.



TIMBER DECAY

Fig. XIII—13.

Defects in Timber Caused By Insects ad other Animals

Insects

Insect borers and termites together constitute one of the most destructive biological agencies causing defects in timber. Some insects infest standing trees, others felled logs before conversion, while some others infest converted timbers including stored timbers. The damage is visible in the form of tunnels and wood-dust-packed galleries in timber. Damage to felled logs may not be apparent until the logs are converted, or seasoned wood is planed or cut for use. Due to insect damage the strength of timber is impaired and continuous infestation causes its complete destruction. Most of these insect borers and termites are polyphagous. Only sapwood is susceptible to most of the borers. Well seasoned heartwood of many species of wood is immune to insect borer attack is service. Some of the more common types of insect attack and the characteristic features of defects caused by them in timber are given in the Table XIII-1, towards the end of this chapter.

Borers

The borer species differ in different climatic regions and many species are not restricted to the country of their origin. Insect borers of tropical regions are complex with high incidence of attacks as compared to those of temperate regions. They are widely distributed and are found even at high altitudes. Insect borers may be classified under powder-post borers, pinhole and shothole borers (bark beetles), and large borers belonging to the families Cerambycidae, Buprestidae and Curculionnidae (order Coleoptera) and Cossidae (order Lepidoptera). The better known defects caused by borers are briefly described below.

Powder-post borers belong chiefly to the families Bostrychidae and lyctidae and are of great economic importance to forestry and wood-using industries. They attack both unseasoned and seasoned wood, but the damage is restricted only to the sapwood region. Manufactured articles of sapwood such as furniture, plywood, matchwood, packing-cases, tent poles, tent pints, tool handles, sports goods, lance staves, etc., are highly susceptible to this group of borers. Presence of starch content in woods is the necessary factor for infestation by the powder-post beetles. Typical examples of this group of borers are *Lyctus*, *Sinoxylon*, *Heterobostrychus*, etc. The emergence holes of Lyctidae are up to 1.5 diameter, and those of Bostrychidae up to 6 mm. In cross-section, these holes are circular in outline and packed with fine wheat-flour-like wood-dust. In the longitudinal section, the tunnels appear cylindrical, packed with fine wood-dust. As the attack is restricted only to sapwood of the logs, the attacked sapwood zone usually goes off as side wastes during normal conversion of timber which is sound for utilization. When selecting timber for constructional or other purposes, powder-post damage should not be ignored as the beetles may continue to be active long after the timber is put into service. Sterilization for two hours of green wood with steam at 54°C (130°F) and of wood with a lower moisture content at 82 °C (180 °F), under controlled conditions of relative humidity, is usually effective in the case of 2.5 cm thick planks. Thicker material requires a longer time. A three minute soaking in, or spraying with, 5% PCP, 5% DDT or 1% Dieldrin, either as emulsion in water or solution in oil, is effective in preventing powder-post damage. Since the beetles lay their eggs in the open pores of the wood, infestation can be prevented by covering the entire surface of wood with a suitable protective finish. Once the wood is infested, the larvae will continue to work even though the surface is subsequently painted oiled, waxed or varnished.

Bark beetles (also called Ambrosia beetles, pinhole and shothole borers) attack weak trees, recently felled trees, and logs in *with-bark-on* condition. Infection occurs in the forest initially. Under forest shade, the infection is heavy ; in the open sun the incidence is less. The infestation in timber from forest is carried to the mills and depots. For development of pinhole and shothole borers (bark beetles), moisture in timber is essential. Typical examples of bark borers are *Xyleborus*, *Platypus*, etc. The defect in timber due to attack by bark beetles appears as pinholes and shotholes. The physical strength of the timber is not impaired, but it is made unfit for such forms of use as face veneers in plywood, match-sticks, decorative planks, etc., where a good appearance is of importance. Preventive methods include quick seasoning of timber after felling, reducing the moisture content down to 12%, debarking soon after felling and exposure to the sun, and chemical prophylatic methods such as immersion or spraying of the freshly felled logs with a solution containing 0.075 to 2% of gamma BHC in fuel oil, or 2% Dieldrin emulsion in water, or 5% DDT suspension in water.

Flatheaded borers belonging to the family Buprestidae are long whitish legless grubs, with a small head withdrawn into the prothorax which is widened into a large flat oval or semi-circular disc. These borers attack timber in *with-bark-on* condition. Infestation takes place in the forest and is carried down to the mills and depots. Only sapwood is ruined. Holes are elliptical in shape having a diametei up to 11 mm. Larval galleries, packed with fine wood-dust, appear elliptical in cross-section and cylindrical, shallow and flat in the longitudial section. Typical examples are *Belionota, Chrysobothris* and *Sphenoptera*. Debarking soon after felling prevents attock by this group of borers.

Longhorn borers belonging to the family Cerambycidae attack timber in *with-bark-on* conditions. The infection takes place in the forest and is carried over when timber is transported down to mills and depots for disposal. Bark, sapwood and heartwood are liable to be ruined owing to excessive riddling by larvae. Seriously damaged timber is useless from the utilisation point of view. Emergence holes are elliptical, oval or circular, having a diameter up to 12 mm. Larval galleries in timber are cylindrical, wide and deep, and packed with relatively coarse-shareded wood-dust. Typical examples are *Aeolesthes, Xylotrechus*, etc. Debarking soon after felling is the only method by which this type of damage can be avoided. Other measures like chemical prophylaxis, sterilization, etc., can also be helpful. *Stromatium barbatum*, a drywood longhorn borer, attacks only dry timber, manufactured articles, constructional timber, etc. The attack is confined only to sapwood which is completely ruined and converted into wood-dust. The affected timber collapses suddenly without any previous indication. Emergence holes are oval, having a diameter up to 7 mm. Galleries are irregular in shape and are packed with wood-dust. Wood preservation is the only method against this borer. The exisiting infection can be sterilized by treatment with preservatives and insecticides.

Carpenter Bees

Carpenter bees (*Xylocopus.* spp.) bore in timber holes similar to those drilled with the help of a carpenter's auger. A colony of carpenter bees, that has occupied a piece of timber continuous for several generations until the wood is completely perforated and riddled with tunnels. Some dry structural timbers, such as haldu (*Adina cordifolia*), jaman (*Syzygium cumini*), and figs (*Ficus* spp.), are attacked by carpenter bees. Heavy incidence of carpenter-bee holes affects the strength and aesthetic value of timber. Emergence holes are circular and clean and, have a diameter up to 20 mm.

Termites

Termites, by their gnawing propensity, from a group of their own. There are abaut 200 species of termites in India. Their main food is cellulose ond, therefore, they consume all material that contains cellulose. Biologically, there are two types of termites, viz, drywood termites and subterranean termites.

The drywood termites live exclusively in dry, sound, seasoned timbers; they do not maintain any conatact with the ground for moisture and thus can easily be dispersed from their their original habit to new localites. For example, the American powder-post termite, *Cryptotermes dudleyi* (family Kalotermitidae), is now a serious pest longthe coastal region of Bengal. The subterranean, or soil-dwelling termites live partly or wholly in the ground and maintain contact with it by means of earthen runways. The notorious subterranean termite of North India, *Heterotermes indicola* is repotted to hhve destroyed an entire township in Punjab. It readily attacks wood in contackt with the ground and also builds covered runways over impentrable obstructions, thus reaching wood not in contact with ground. The subterranean termites are responsible for most of the damage done to wood in India.

Atmospheric temperature plays the most dominant role in the dispersal and distribution of termites. A temperature of 27°-30 °C is considered optimum for the majority of the tropical species of termites. No termite can thus tolerate low temperature. All termites need high atmospheric humidity nearing saturation. Subterranean termites maintain high humidity in their galleries through soil contact, in the absence of which the colony cannot survive.

The best protection against subterranean termites is to build structures in such a way that their access into the building is prevented, and connection of soil with timber, directly or indirectly, is cut off. There are several measures to achieve this. Soil sterilization with soil insecticides such as 2% Dieldrin, 0.7% gamma BHC etc., and use of wood preservatives such as Ascu, creosote, etc., are recommended. Heartwood of certain woods naturally resistant to termites, such as deodar (*Cedrus deodara*), mesua (*Mesua ferrea*), sal (*Shorea robusta*), teak (*Tectona grandis*), etc., can be used. When a building stands on pillars, the use of metal termite shield is effective against subterranean termites.

Other Animals

Marine borers

Wood-boring marine animals of economic importance belong to two classes, viz., crustaceans and bivalve molluscs. They are of importance only in coastal regions in respect of wood stored in saline and brackish water.

Crustaceans.—In this class are *Limnoria*, *Chelura* and *Sphaeroma*. Their method of attack and the general effect on the timber is similar. *Limnoria* (the 'Gribble') attacks the surface of wood and destroys it by gnawing, interlacing and branching burrows which are generally 1.3 mm in diameter. Their burrows are so numerous that the surface layers of timber are quickly destroyed. The greatest intensity of attack is between low tide and half-tide marks. Creosoted timber is readily attacked. The galleries bored by *Chelura* and *Sphaeroma* are much larger than those of *Limnoria*. *Sphaeroma* is not very destructive to wood.

Bivalve molluscs.—The important genera in this class are *Teredo*, *Bankia* and *Martesia*. Several species of these genera attack timber in sea-water. The attack and general appearance of the first two genera are similar. They are popularly known as "shipworms" because of their soft, long, worm-like body. The shell which is at the head functions as a highly specialized boring mechanism. The burrows are lined with a thin calcareous coating which protects the delicate body of these animals. *Martesia* is pear-shaped and its body is wholly enclosed within a bivalve shell. The breeding habits and the life-history of these moluscs are similar. The larva has a bivalve shell and swims freely in sea-water. It attaches itself to submerged wood into which it bores by scraping away the surface with its shell. The entrance hole is very small and the animal grows with remarkable rapidity, enlarging its burrow in the wood as it increases in size. The tunnels excavated inside are sometimes 1.3 cm in diameter. Piles and other wooden structures are thus completely riddled with tunnels without showing any external sign of attack. The damage by *Martesia* is sometimes visible from the outside. Practically all kinds of timber are destroyed by these marine borers. Satisfactory protection against them is obtained by the impregnation of timber with pure creosote under pressure. Provision of metal sheathing, or concrete or metal casing, to the submerged woodens structure is effective so long as the sheathing or casing remains intact.

TABLE

Types of borer defects in timber : Description of defects and suggestions to

Type of borer defect	Group of borers	Typical examples of borers	Description of type of defect
1	2	3	4
Pinholes and shotholes of Ambrosia boiei type	Scolytidae and Platypodidae (Bark borers)	*Xyleborus*, *Platypus*	Holes up to 4 mm in diameter. Holes circular in cross-section, stained black. Tunnels in longitudinal section appear as black stained straks. Holes and tunnels contain no wood-dust.
Pinholes and shotholes of powder-post borer type	Lyctidae and Bostrychidae (powder-post borers, timber ghoon, bamboo ghoon)	*Lyctus*, *Sinoxylon*, *Hetero-bostrychus*, *Dinoderus* (bamboo ghoon)	Pinholes up to 1.5 mm in diameter (emergence holes of Lyctid beetles), and shotholes up to 6 mm in diameter (emergence holes of Bostrychid beetles). In cross-section the holes are circular, packed with fine wheat-flour-like wood-dust and restricted to the sapwood zone only; on tapping the dust falls on ground. In longitudinal section, the tunnels appear cylinderical pack with fine wood-dust and restricted to the sapwood zone.
Worm holes, grub holes, borer holes of the large Cerambycid borer type.	Cerambycidae (large borers)	*Hoplocerambyx*, *Aeolesthes*, *Xylotrechus*	Elliptical, oval or circular holes ranging up to 12 mm in diameter. Larval galleries (tunnels) in timber are cylindrical, wide and deep in sapwood and heartwood, packed with coarse-shredded wood-dust.
Damage by flatheaded borer	Buprestidae (flatheaded borers)	*Sphenaptera*, *Chrysobothris*	Elliptical holes up to 11 mm in diameter, In cross-section, larval galleries appear elliptical, packed with fine wood-dust; larval galleries in longitudinal section are cylindrical, shallow and flat, packed with wood-dust.
Damage by dry timber borer	Cerambycidae (dry timber borer)	*Stromatium barbatum*	Oval holes up to 7 mm in diameter and galleries irregular in shape ; packed with wood-dust.

XIII.1

Prevent them in timber and to retrieve sound timber

How and when defects occur	Conditions of affected timbers, physical or aesthetic	Suggestions to prevent defects, if any
5	6	7
Ambrosia beetles attack weak trees, recently felled trees and logs *with-bark-on* condition. Infection occurs in forest initially. Under forest shade the infection is heavy, and in open sun the incidence is less. The infection in timber is carried from forest to the mills and depots. For the development of Ambrosia borer, moisture in timber is essential.	Physical strength of timber is not impaired, but it is made unfit for finer utilisation like plywood, match-sticks, decorative planks, etc., because aesthetic aspect is marred by pinholes and black stains.	Quick seasoning of timber after felling is necessary. Moisture in timber must be reduced to below 10% by this process. Debarking soon after felling and exposure in sun on skids in recommended. Keeping the logs in the open and rotating them frequently to secure uniform warmth is helpful. Chemical prophylaxis is also recommended.
Borers attack timber undergoing natural seasoning, seasoned timber, and manufactured articles. Infection occurs in storage yards, mills, factories and depots. Lyctid can attack only pored dry timber including manufactured articles.	Only sapwood zone of timber is attacked and the attack is restricted to that part of it which contains starch and soluble sugars (carbohydrates); rest of the sapwood is not attacked. The attacked depth zone of sapwood usually goes off as side wastes during normal fashioning of timber. The timber recovered after conversion is sound for utilization.	Powder post damage can be prevented and cured by water seasoning, chemical prophylactic measures, natural storage methods, and wood preservation.
Cerambycids attack timber *with-bark-on* condition. This attack takes place in forest and infection is carried over when timber is transported to mills and depots for disposal.	Bark, sapwood and heartwood are liable to be ruined owing to excessive riddling by larvae, Seriously riddled timber is rendered useless from the utilization point of view.	Debarking soon after felling is recommended, and is the only method to avoid this type of borer damage. Other measures like chemical prophylaxis, sterilization, etc., can also be helpful.
Borers attack timber *with-bark-on* condition. Infection takes place in forest and is carried down to the mills and depots.	Only sapwood is ruined.	Soon after felling, debarking is recommended.
Attack occurs only in dry timber; manufactured articles, constructional timber, etc.	Restricted to sapwood which is completely ruined, being converted in to wood-dust. The timber collapses suddenly without any previous indication.	Wood preservation is the only method against this borer. The existing infection can be eradicated by wood preservation and application of insecticides.

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1	2	3	4
Carpenter bee holes	Xylocopidae (Carpenter bees)	*Xylocopa*	Circular clean holes up to 20 mm in diameter; liable to be mistaken for a hole drilled by carpenter's auger in timber.
Termite damage	Isoptera (White ants, termites)	*Heterotermes*, *Odontotermes*	Large irregular cavities and ridges along the wood grain are eaten into and filled with earth (clay like excrement).
Marine wood-borer type	Mollusca, Crustacea (Shelly borers)	*Teredo*, *Martesia*, *Limnoria*	Surface pinholing to complete riddling and honey-combing of timber. The tunnels lined with white calcareous deposits or tubes. Attack occurs only in timber stored in salt or brackish water in sea-coasts.
Other types of defects in timber due to damage in the tree stage	Coleoptera, Lepidoptera, Isoptera, higher vartebrates (Insects, mammals)	Coccid borers, Cerambycid borers, termite, etc., and wild animals	Knots, hollow, tunneles, etc., are some types of defects in timber that may be revealed after conversion of apparently sound tree.

5	6	7
Dry structural timber of even texture is attacked.	Heavy incidence of carpenter-bee holes affects the strength and appearance.	Use of pressure-treated timber is recommended. Chemical prophylaxis is also a helpful measure.
Termites attack wood directly where it is in contact with the ground, and indirectly through earthen runways in other cases. Termites are subterranean in habit and depend upon soil moisture.	All forms of timber (log, rafters, furniture, plywood, beams, pillars, posts, etc.) are ruined and the damage remains hidden. This is followed by a sudden collapse, particularly of structural timbers in use. Their chief food is cellulose and all cellulosic articles are damaged.	Cut off from the timber the direct or indirect soil connection. There are several measures to achieve this. It will help to consult experts in this connection. Chemical methods, soil sterilization and poisoning, and use of the heartwood of naturally termite-resistant timbers or pressure-treated timbers are recommended.
Attack takes place only in sea-water, and the incidence of attack is governed by salinity and temperature of water.	All timbers are heavily riddled, and become unfit for use.	Special techniques are available to minimise attack. Experts to be consulted.
Some of the defects may be of insect origin, caused when tree is standing.	——	Retrieve through conversion what is left as sound timber. Preventive steps are silvicultural-cum-biological.

Birds and Mammals

In birds, only wood-peckers do some damage to individual trees by excavating holes in stems and branches for laying eggs or for discovering the grubs of borers for food.

Some of the animals, e. g., deer, bears, etc. cause serious wounds by peeling off the bark and damaging the cambium. This results in the formation of abnormal tissues which sometimes make for defects in the timber.

REFERENCES

Anon 1957 British Commonwealth Forest Terminology, Part II; Empire Fo estry Association, London.

Anon 1950 Forestry Terminology—A Glossary of Technical Terms; Society of American Foresters, Washington.

Bagchee, K. D. 1951 Some fungi as wound parasites on Indian trees; *Indian For. Rec.* (N.S.), 1 (1), Mycology; Manager of Publications, Delhi.

Bagchee, K. D. 1960 Indian timber and its decay; *Indian For. Rec.* (N.S.), 2 (6), Mycology; Manager of Publications, Delhi.

Bagchee, K. D. & Singh, U. 1960 List of common names of fungi attacking Indian foresttrees, timber and the herbaceous and shrub by undergrowths; *Indian For. Rec.* (N.S.),1(10); Mycology; Manager of Publications, Delhi.

Bailey, I. W. & Vestal, Mary, F. 1937 The significance of certain wood-destroying fungi in thestudy of enzymatic hydrolysis of cellulose; *J. Arnold Arbor.*, 18; Harvard University, Lancaste Pa.

Bakshi, B. K. 1951 Studies on four species of *Ceratocystis* with a discussion on fungi causing sapstain in Britain; Mycological Institute, Kew, Surrey.

Bakshi, B. K. 1956 Principles of tree disease control with reference to Indian forests; *Indian For. Bull.* (N.S.), No. 193, Mycology; Manager of Publications, Delhi.

Bakshi, B. K., Guha, S. R. D. & Gupta, S. 1960 Effects of fungal damage to bamboo on the yield and quality of pulp; *Research & Industry*, 5 (2); Council of Scientific & Indust ial Research, Delhi.

Baxter, D. V. 1952 Pathology in Forest Practice; John Wiley & Sons, Inc., New York.

Beeson, C. F. C. 1961 The Ecology and Control of Forest Insects of India and the neighbouring Countries; Manager of Publications, Delhi.

Boyce, J. S. 1960 Forest Pathology; McGraw-Hill Book Company, New York.

Brown, H. P., Panshin, A. J. & Forsaith, C. C. 1952 Textbook of Wood Technology, Vol. II; McGraw-Hill Book Company, New York.

Desch, H. E. 1953 Timber, its Structure and Properties; Macmillan, London.

Duncan, Catherine G. 1960 Soft rot in wood, and toxicity studies on causal fungi; *Proc. Amer. Wood Pres. Ass.*, Baltimore, Md.

Findlay, W. P. K. 1950 The resistance of wood-rotting fungi to desiccation; *Forestry*, 23 (2); Oxford University Press, London.

Findlay, W. P. K. 1956 Timber decay—a survey of recent work; *For. Abstr.*, 17 (3 & 4); Commonwealth Agricultural Bureaux, England.

Findlay, W. P. K. 1959 Sapstain of timber; *For. Abstr.* 20 (1 & 2); Commonwealth Agricultural Bureaux, England.

Findlay, W. P. K. & Badcock, E. C. 1954 Survival of dry rot fungi in air dry wood; *Timber Technology & Machine Wood Working*, 62; London.

Gardner, J. C. M. 1945 Insect borers of bamboos and their control; *Indian For. Bull.* (N.S.), No. 125, Entomology; Manager of Publications, Delhi.

31 AUG 1987

I. S. I. 1959 Glossary of terms applicable to timber, plywood and joinery, IS : 707 1958; Indian Standards Institution, Delhi.

Puri, Y. N. 1955 Rust and wood rotting fungi on some of the important Indian conifers; *Indian For. Bull.* (N.S.), No. 179, Mycology; Manager of Publications, Delhi.

Roonwal, M. L., Bhasin, G. D., Mathur, R. N. & Singh, Balwant 1954 to 1961 A list of insect pests of forest plants in India and the adjacent countries; *Indian For. Bull.* (N.S.), No. 171 (1—9), Entomology; Manager of Publications, Delhi.

Savory, J. G. 1954 Breakdown of timber by Ascomycetes and Fungi Imperfecti; *Ann. Appl. Biol.*, 41 (2); Cambridge.

Stebbing, E. P. 1914 Indian Forest Insects of Economic importance; H. M.'s Secretary of State for India in Council.

Trotter, H. 1940 Manual of Indian Forest Utilization; Oxford University Press, London.

Troup, R. S. 1912 Indian Forest Utilization; Superintendent of Government Printing, Calcutta.

PART III

WOOD IMPROVEMENT AND PHYSICAL AND CHEMICAL TREATMENT

CHAPTER XIV

SEASONING OF WOOD

Introduction

Apart from the operations of felling, conversion and selection, wood neeeds a certain amount of processing before use for satisfactory performance. Such processing is essential for economic and rational utilization of timber resources; its importance is now better appreciated with the keen competition which wood has to face against other structural raw materials like steel, aluminium and synthetic materials such as plastics etc.

The proper seasoning of wood before use is one of the most important factors in its efficient and rational utilization. It forms an essential part of the processing of wood for its satisfactory utilization for most purposes. Barring a few uses such as floaters, fenders, etc. there is hardly any use for which some degree of seasoning of the wood prior to use is not called for. For all purposes where retention of shape and size of the finished product in service is essential, through seasoning of wood before manufacture is a prime necessity. Seasoning also helps to reduce considerable losses of wood through surface cracking splitting, warping etc., in storage, transit and service, besides improving several of its properties. The seasoning of wood is thus a problem which concerns foresters, manufacturers and users alike. In advanced countries, investment on seasoning has come to be regarded as an indispensable part of the aggregate cost of production of timber.

What is seasoning?—Wood in growing trees contains considerable quantities of water. Most of this water has to be removed in order to obtain satisfactory performance from the wood in use. Seasoning of timber is essentially a process of drying it, as nearly as possible, to the moisture content it will attain in use or, in other words, to a suitable moisture content warranting equilibrium with the prevailing atmospheric conditions in service.

During the removal of this moisture the wood shrinks and, if the process of drying is not properly carried out in a controlled manner, this shrinkage is liable to give rise to defects such as surface cracking, end-splitting, warping, etc. (see Chapter XIII). Under unsuitable conditions of drying, timber may also suffer biological deterioration such as decay, mould growth or sapstain, or deterioration in strength. A proper and efficient seasoning process is designed to achieve controlled drying of timber to the required moisture content, in the shortest possible time and consistent with minimum of degrade.

Objects and importance of seasoning.—An important object of seasoning timber is to dry it to the equilibrium moisture content before use, so that gross dimensional changes through shrinkage, which inevitably occur in green wood as it tends to attain equilibrium with the surrounding atmosphere, are eliminated. By seasoning timber, so as to conform to the optimum moisture content (i. e. the mean of the maximum and minimum moisture contents which will be attained by wood in service under fluctuations of climatic conditions), "movement" in the components of the finished product, relative to the dimensions at the time of fabrication, is also kept to a minimum (see Chapter XII). Thus seasoning is the first step towards realizing maximum attainable dimensional stability from any timber during use.

Considerable losses through cracking, splitting, warping, etc., which are liable to occur while using green timber under inevitable exposure to surrounding uncontrolled climatic conditions, are avoided by carrying out proper seasoning under controlled drying conditions prior to use. This is of great importance in timber utilization in India where the climatic conditions vary considerably at different times of the year.

Seasoning, if carried out promptly after the felling of trees, also protects timber against primary decay, fungal stain and attack by certain kinds of insects. The organisms, which cause decay and stain, generally cannot thrive in timber with moisture content below 20%. Several, though not all, insect pests can live only in green timber. Seasoned wood is less susceptible to decay than green wood in indoor use,

as there is generally less chance of the moisture content again increasing above 20% by reabsorption from the surrounding atmosphere.

Apart from the above important advantages of seasoning of timber, the following may also be mentioned :

(i) Seasoned timber is lighter and hence the transport and handling costs are reduced.

(ii) Seasoned timber is stronger than the green timber in most of the strength properties.

(iii) Timbers which are to be impregnated with preservatives have to be properly dried if proper penetration is to be accomplished, particularly in the case of oil-type preservatives.

(iv) Seasoned wood-work finishes and glues better than green timber. Paints and finishes last longer on seasoned timber.

(v) The electrical and thermal insulation properties of wood are improved by seasoning.

It is thus evident that prompt seasoning of wood immediately after felling and conversion of trees, results in significant upgrading of the raw timber. Therefore all timbers—no matter whether they belong to primary species of teak class or secondary species like mango, jaman, etc., whether they belong to naturally durable (resistant to fungal decay and insect attack) class like sal and deodar or non-durable class like mango and chir, and whether they consist of heartwood or sapwood—require to be seasoned. Seasoning enables substantial long-term economy in utilization by minimising replacements, besides rationalizing the utilization of our timber resources.

General Principles of Seasoning

The chief difficulty experienced in the seasoning of timber is the tendency of its outer layers to dry out more rapidly than the interior. If these layers are allowed to dry much below the fibre saturation point, while the interior is still saturated, stresses (called *drying stresses*) are set up, because the shrintkage of the outer layers if restricted by the west interior. Rupture in the tissues of wood and, consequently, splits and cracks occur if these stresses exceed the strength.

The successful control of drying defects in a drying process consists in maintaining a proper balance between the rate of evaporation of moisture from the surface and the rate of outward diffusion of moisture from the interior of the wood, so that the surface moisture content does not fall too low right in the initital stages of drying. In most species, excepting the highly permeable ones, the rate of moisture diffusion lags behind the rate of surface evaporation, probably soon after drying begins, with the result that the surface dries to a moisture content close to equilibrium moisture content condition of the drying air right in the initial stages of drying. This equilibrium moisture content depends upon the temperature and relative humidity of the drying air, and needs to be maintained sufficiently high in the early stages of drying for limiting the severity of drying stresses and consequent checking and splitting. The extent to which such control of drying conditions is necessary differes widely from species to species, depending upon the resistance which the wood offeres to the diffusion of moisture. Generally, thicker sections of timber need greater care in this regard than the thinner ones.

The rate of drying of wood is governed any interaction of the external drying conditions, viz., temperature, relative humidity, rate of air criculation, and the rate of moisture diffusion within the wood, as detailed below :

Temperature.—If relative humidity is kept constant, the higher the temperature the higher is the drying rate. Temperature influences the drying rate by increasing the moisture-holding capacity of air, as well as by accelerating the rate of diffusion of moisture through the wood.

Relative humidity.—If temperature is kept constant lower relative humidities result in higher drying rates. This is effected by the increased moisture gradient in wood, resulting from the reduction of moisture content of surface layer when the relative humidity of air is reduced.

Air circulation.—With constant temperature and relative humidity, the highest possible drying rate is obtained by rapid circulation of air across the surface of the wood. This is brought about by the rapid removal of moisture evaporating from the wood, so that the relative humidity of air in contact with wood is not allowed to rise beyond the relative humidity being maintained in the body of the drying air.

Species.—Some species dry much faster than others. This is mainly related to the resistance which wood offers to moisture diffusion, which is governed by the dimensions, alignment and structure of the capillary system of wood, and the nature and extent of plugging of this structure by gums, extractives, organic growths like tyloses, pit aspiration, etc.

Initial moisture content.—The amount of moisture contained in the wood affects the time required to bring it to a given moisture content. As a general rule, wood dries at a faster rate when green. The rate decreases with decrease of moisture content under constant drying conditions. This is because initially the evaporation from green wood is confined to the surface layers, which can dry by direct evaporation of the moisture into the surrounding air. Sooner or later, however, the rate of outward diffusion of moisture within the wood becomes the controlling factor as moisture has to be brought out from the interior to the surface for further evaporation.

Grain direction.—Wood dries much more rapidly in the longitudinal direction than in the transverse direction. The rate of drying from end-grain is from 10 to 15 times as fast as it is from the radial or tangential surfaces. In practice, however, timber is mostly sawn with its length conforming to the general direction of the grain and with the width and thickness transverse to the grain. Because of the large difference between longitudinal and transverse dimensions, drying of timber in common commercial sizes occures mostly from its lateral faces by transverse movement rather than from the end-grain faces by longitudinal movement of moisture.

Thickness.—Thicker timber requires more time to reach a given moisture content than the thinner timber.

Methods of Seasoning

Seasoning of timber is essentially a drying process. The technique most widely adopted consists in circulation of air, in the unsaturated state, over the surfaces of timber to evaporate and remove moisture. The air serves both as a carrier for the heat required for evaporation of moisture from the timber and as a vehicle for the removal of evaporated moisture from the timber surfaces. Two methods based on this principle, which are most widely practiced, are "Air-Seasoning" and "Kiln-Seasoning".

A number of other techniques have been tried, in recent years, to achieve accelerated seasoning or improved quality of drying, with regard to drying defects, as compared to conventional kiln-seasoning. None of these has yet found wide commercial application, either because they are not universally applicable or because of their higher cost or complexity of the equipment required. These methods are described later in this chapter under the caption "Special Seasoning Methods".

A brief mention may also be made here of certain common practices or procedures in timber utilization, which are sometimes erroneously understood to be methods for seasoning of timber. The storage of logs under water is sometimes known as *water-seasoning*, which is obviously a misnomer, as no drying can possibly take place so long as the logs are under water. It is sometimes claimed that if the logs are kept under water for a number of years before conversion, the wood subsequently dries

more rapidly and with less degrade than unsoaked wood. In limited systematic trials carried out to test the efficacy of this procedure, the improvement in properties affected was neither significant nor consistent to justify the increased expense of storing logs or timber for long periods under water before seasoning. The practical utility of this procedure is, strictly speaking, confined only to the protection of logs from cracking, splitting, insect and fungal attack (as a result of leaching out of water-soluble substances, such as starch) during storage for long periods.

Partial drying of wood is sometimes effected, before the tree is felled, by girdling the trunk. By the term "girdling" is meant the cutting of a ring near the base of a tree, the ring being about 15 cm wide and 2 cm to 5 cm deep, from which all traces of sapwood are removed. Sap passes up a tree through the sapwood only, and the removal of sapwood in a circle round the tree effectively prevents the upper part of the tree from obtaining nourishment and kills it. In the extraction of teak in Burma, girdling is the standard practice, the trees being left standing after girdling for two to three years, during which period the wood loses a considerable part of its moisture, with the result that the logs become floatable and their transport by water is facilitated. It may, however, be clearly understood that girdled teak is by no means fully seasoned and that converted material obtained from girdled teak should be further seasoned before use, as any other timber. Experiments carried out at the Forest Research Institute, Dehra Dun, on a number of hardwood species clearly show that at the end of two to three years' girdling, the moisture content is above the fibre saturation point except in the sapwood. The initial moisture content of the trees varied between 100 and 120 per cent and the final moisture content after 2½ years' girdling was still between 30 and 45 per cent in the heartwood. The sapwood showed a lower moisture content, but it was rendered useless for any practical purposes on account of severe surface cracking and borer attack. The trees were found to have died in a year after girdling and the bark of the girdled trees also fell off during the same period. It was also observed that the girdled trees had a tendency to break across during felling, probably because there was no cushioning effect of the branches. There was no difference in the quality of material obtained from the ungirdled trees and from those girdled for three years. The seasoning behaviour of the material obtained from the two lots was also the same. Entomological investigations on the girdling of *Hopea* species indicate that girdling is a dangerous practice leading to mass production of a dangerous beetle.

It may be stated, in a general way, that the girdling of trees has no particular advantage from the point of view of seasoning, and should not be adopted as a standard practice unless considered necessary for the purpose of making logs floatable. Some species, e.g., *Adina cordifolia, Lagerstroemia tomentosa* and *Homalium tomentosum* cannot be easily killed by girdling.

Classification of Indian Timber for Seasoning Purposes

Based on extensive observations of seasoning degrade and rates of drying, Indian timbers have been classified into the following three classes according to the ease or difficulty with which they season. This classification is, of course, arbitrary and is meant to give only an approximate idea of the nature of the species with regard to their seasoning behaviour.

(a) *Class A : Highly refractory woods.*—They are slow and difficult to season free from defects, particularly cracking and splitting. Examples are heavy structural timbers such as sal (*Shorea robusta*), laurel (*Terminalia tomentosa*), axlewood (*Anogeissus latifolia*), hopea (*Hopea* spp.) etc. They require a good deal of protection against rapid drying conditions for the best results.

(b) *Class B : Moderately refractory woods.*—They show moderate tendency to crack and split during seasoning. They can be seasoned free from defects with a little protection against rapid drying conditions. Examples are the furniture class timbers such as sissoo (*Dalbergia sissoo*) and teak (*Tecton gradis*).

(c) *Class C : Non-refractory woods.*—They can be rapidly seasoned free from defects even in the open air and sun. If not dried rapidly, they develop discoloration (blue stain) and mould on the surface. Examples are packing case timbers such as semul (*Bombax ceiba*), salai (*Boswellia serrata*), mango (*Mangifera indica*), gutel (*Trewia nudiflora*), etc.

This classification, according to the refractoriness of timbers to seasoning, is given in the following Table XIV-1 for a number of species. The kiln schedule, referred to under kiln-seasoning later in this chapter, is also indicated for each species.

TABLE XIV-1

Classification of some important Indian timbers with regard to their seasoning behaviour and the kiln-schedule applicable to them.

Source : Code of Practice for Seasoning of Timber—IS : 1141—1958

Sl. No.	Species	Class (Refractoriness)	Kiln Schedule
1	2	3	4
1.	*Abies pindrow*	C	I
2.	*Acacia nilotica* (*A. arabica*)	B	VI
3.	*Acrocarpus fraxinifolius*	B	III
4.	*Adina cordifolia*	B	V
5.	*Ailanthus excelsa*	C	I
6.	*Albizia lebbeck*	B	IV
7.	*Albizia procera*	B	IV
8.	*Alstonia scholaris*	C	I
9.	*Artocarpus chaplasha*	B	III
10.	*Artocarpus hirsuta*	B	IV
11.	*Bischofia javanica*	A	IV
12.	*Bombax ceiba*	C	I
13.	*Boswellia serrata*	C	II
14.	*Buxus sempervirens*	B	V
15.	*Calophyllum* sp.	B	IV
16.	*Canarium euphyllum*	C	I
17.	*Cassia fistula*	A	VII
18.	*Cedrela toona*	B	V
19.	*Cedrus deodara*	C	III

1	2	3	4
20.	*Chloroxylon swietenia*	A	VI
21.	*Dalbergia latifolia*	B	IV
22.	*Dalbergia sissoo*	B	IV
23.	*Dipterocarpus turbinatus*	B	V
24.	*Diospyros melanoxylon*	A	VI
25.	*Eucalyptus globulus*	A	VI
26.	*Fagara budrunga*	B	V
27.	*Gmelina arborea*	B	III
28.	*Grewia tiliaefolia*	A	VI
29.	*Holarrhena antidysenterica*	B	III
30.	*Holoptelea integrifolia*	B	III
31.	*Hymenodictyon excelsum*	B	III
32.	*Juglans regia*	B	V
33.	*Kingiodendron pinnatum*	B	V
34.	*Kydia calycina*	C	II
35.	*Lagerstoremia lanceolata*	B	IV
36.	*Lannea coromandelica*	B	III
37.	*Mangifera indica*	B	II
38.	*Michelia champaca*	B	III
39.	*Mitragyna paryifolia*	B	V
40.	*Morus australis* (Syn. *M. indica*)	B	IV
41.	*Ougeinia oojeinensis*	B	VI
42.	*Palaquium ellipticum*	B	IV
43.	*Picea smithiana*	C	I
44.	*Pinus roxburghii*	C	II
45.	*Pinus wallichiana*	C	II
46.	*Pterocarpus dalbergioides*	B	IV
47.	*Pterocarpus marsupium*	B	VI
48.	*Shorea robusta*	A	VII
49.	*Sterculia campanulata* (Syn. *Pterocymbium tinctorium*)	C	I
50.	*Syzygium cumini*	A	VII

1	2	3	4
51.	*Tectona grandis*	B	VI
52.	*Terminalia belerica*	B	IV
53.	*Terminalia myriocarpa*	B	III
54.	*Terminalia tomentosa*	A	VI
55.	*Tetrameles nudiflora*	C	I
56.	*Trewia nudiflora*	C	I
57.	*Zizyphus mauratiana*	B	VI

AIR-SEASONING

The technique of air-seasoning consists mainly in making a good stack of sawn timber with the help of battens (crossers) on raised foundations, in a clean and dry place, under shade if available. As atmospheric air is the drying agent, the rate and quality of drying largely depend on the climatic conditions. Even so, losses of timber through cracking, splitting, warping, decay through fungal and insect attack can be considerably minimised by paying proper attention to the method of stacking, protection of stacks against the sun and hot and dry winds, and sanitary conditions in the yard. These precautions are all the more important if weather conditions are hot and humid or hot and dry.

Necessity of stacking.—Stacking technique is the most important single factor in satisfactory air-seasoning of timber. Proper stacking of timber ensures uniform drying and reduces seasoning degrade considerably, particularly warping and biological deterioration through mould and stain. The rate of drying can be controlled to a certain extent by regulation of the rate of air circulation through the stack by adjusting the height of the foundation, width and height of the stack, thickness of the crossers and spacing between the adjoining planks in a layer to suit individual cases.

Horizontal stacking.—This is the most common method of stacking timber for air-seasoning and is suitable for all forms of sawn material, from thin veneers to thick scantlings, railway sleepers and poles, with slight modifications to suit different conditions as regards species of wood, thickness of material and the climatic conditions of the locality, etc. As a general rule, when stacking non refractory species for air-seasoning in a mild climate, care should be taken to provide a good circulation of air through the stack. On the other hand, in order to obtain best drying results with refractory woods in a hot dry climate, the rate of drying must be kept as slow as possible by adopting measures to decrease the air circulation through the stack.

Planks (Fig. XIV—1).—The stacking should be done on level foundation over skids (longitudinally placed scantlings) of cross section about 10 cm × 10 cm. Crossers should be of seasoned and reasonably strong timber, of uniform thickness and cross-section, say 4 cm×2.5 cm, for stacking planks up to 5 cm thickness. The distance between the successive crossers in a layer should be about 0.6 m for 2.5 cm thick planks. For thicker planks the spacing may be increased to .75 m. Planks thinner than 2.5 cm should be stacked with crossers spaced less than 0.6 m apart to prevent or minimise warping.

The crossers should be in vertical alignment in a stack. This is a very important factor in stacking for control of warping. As far as possible, the stack should be constructed so that the ends and sides of the stack are square, with the ends of timber neatly sandwiched between the line of crossers. This is termed *box piling*. It ensures uniformity of air circulation, retards end drying and prevents end cracking of timber. In the case of mixed lengths, the longest planks should be at the bottom and the shortest ones on the top. In order to cope with the heavy inflow of timber, and also where the stacking operations cannot be stopped for particular lengths of planks, the stacks may be made separately for long, medium and short lengths of timbers. The same holds good for mixed thicknesses also. Heavy beams should be placed at the top of the stack to prevent the top layers from warping. The stacks should be raised to convenient heights. The width of individual stacks should not ordinarily exceed 1.5 m, but if it does, an open space, about 25 cm wide, should be left in the middle of the stack from top to bottom to permit good air circulation in the centre of the stack. Gaps, about 2.5 cm wide, should also be left

between adjoining planks in all the layers to allow vertical movement of air through all portions of the stack.

The stacking should preferably be done under a shed to protect the timber against sun and rain. Improvised roofing made of rejected but sound off-cuts of logs and thatch, covered with mud plaster if nothing else is available, also gives certain amount of protection to the timber from the direct sun and rain. Such improvised roofing should have sufficient overhang to protect the ends of the stack from the direct sun. Protection of the top is very essential when stacking refractory hardwoods for seasoning in a hot and dry locality. It can, however, be dispensed with in the case of non-refractory woods. Faster rates of drying, as required in case of non-refractory species and timbers liable to decay and stain, can be achieved by increasing the gaps between adjacent planks in a layer, by suitably orienting the stacks in such a way that their lengths are at right angles to the prevailing winds and by providing adequate spacing between adjacent stacks in the yard.

Scantlings, squares and flitches.—These should be stacked with crossers 5 cm × 4 cm in cross section kept 2.5 to 3 m apart. The stack should be raised to a convenient height, say up to 3 m. The ends should be coated with moisture proof composition. As far as possible, the width of the individual stack should not exceed 2.0 m.

Poles (Fig. XIV-2).—These should be stacked, after debarking, either in closed heaps or with crossers, depending upon the species and climatic conditions. If stacked in closed heaps, there should be alternate layers, of butt ends and top ends at one end of the stack so as to keep the two ends of the stack level. In the case of non-refractory species, and in mild climate, stacking should be done with crossers, some of the poles themselves being used as crossers.

Railway sleepers.—In order to avoid the use of crossers, which are not easily available in places where railway sleepers are usually stacked, and also to provide, to some extent, the drying conditions suitable for the species of timber, either the 'one and nine' or the 'close crib' method of stacking should be adopted.

In the 'one and nine' method, nine sleepers are laid in each layer allowing gaps between adjacent sleepers. The successive layers are separated from one another by placing one sleeper across (between the layers) alternately at either end of the stack (Fig. XIV-3). This method is suitable for moderately heavy species, particularly coniferous, and in hot climates. All coniferous sleepers in North India should be stacked by 'one and nine' method after being transported by water. Non-coniferous sleepers in moist zones of South India, West Bengal and Assam should also be stacked by this method.

The 'close crib' method consists in simply making a solid stack (without gaps), with the sleepers in alternate layers placed in a criss-cross manner (Fig. XIV-4). It gives slower seasoning as it reduces the air circulation. This method is recommended for stacking sleepers of refractory timber in hot and dry localities, such as sal in Uttar Pradesh and Bihar.

The 'open crib' method (Fig. XIV-5) is a modification of the 'close crib' method in which gaps are allowed between adjacent sleepers in a layer, thus allowing more air circulation. The effect of drying of sleepers by this method is almost the same as in the 'one and nine' method. This is, however, not a common method for stacking sleepers.

Stacks, each containing about 100 sleepers, are recommended. These methods of stacking can also be used for short lengths of thick scantlings.

The timber yard.—The requirements of a good timber yard are as follows :—

Site.—The timber yard should preferably be level, have a direct approach to the main road and always be away from residential areas. The land should be at a higher level with proper drainage. It should be well fenced to prevent cattle from straying inside (so as to avoid dung, which is a serious source of infection). The yard should be maintained under hygienic conditions to minimise incidence of fungal and insect attack to which the timber is exposed during long periods required for air seasoning. It should be kept clear of weeds and undergrowth as these conduce to stagnant humid air around the stacks. It is preferable to have it surfaced with concrete or cinders, gravel, sand or some such material. The layout of the yard should be such as to enable free movement of transport from one

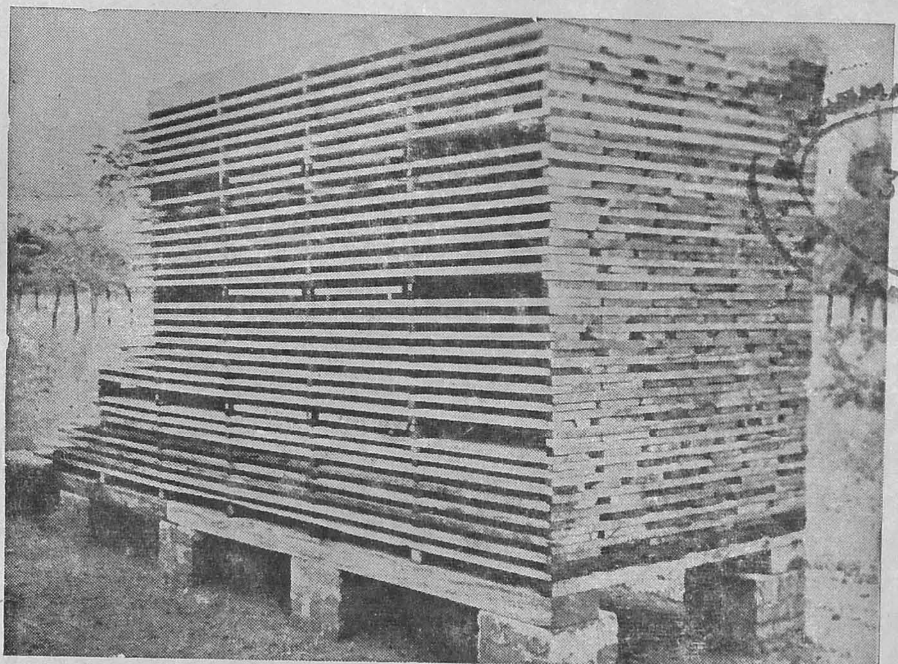

Fig. XIV—1. Horizontal stacking of planks for air seasoning.

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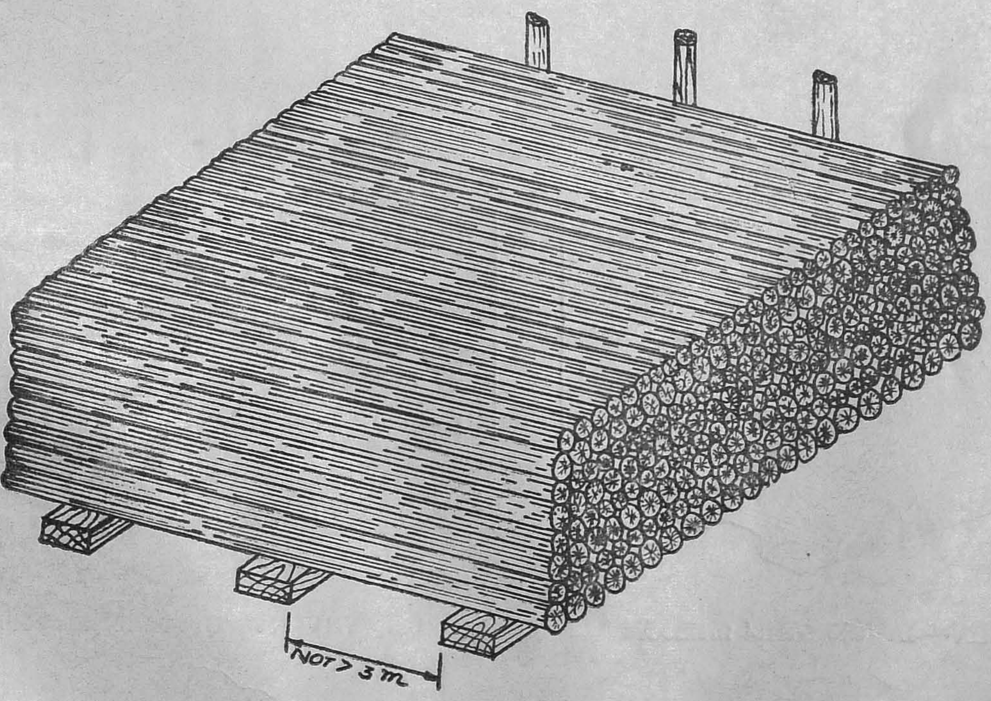

Fig. XIV—2. Stacking of poles.

STACKING OF RAILWAY SLEEPERS

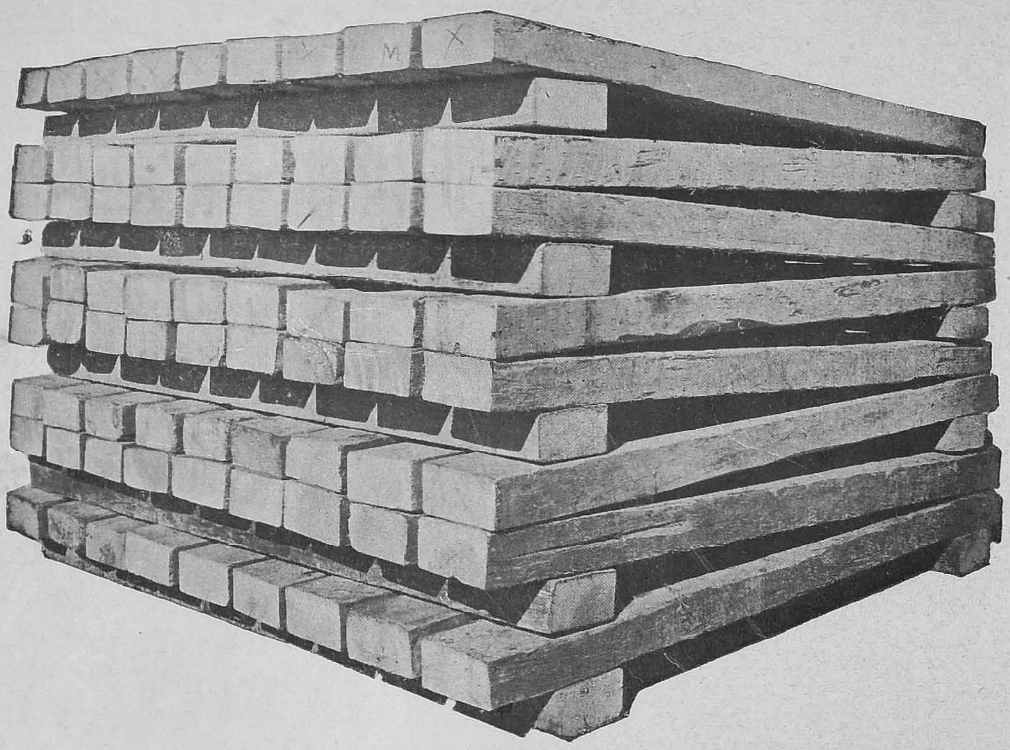

Fig. XIV—3. 'One and nine' method.

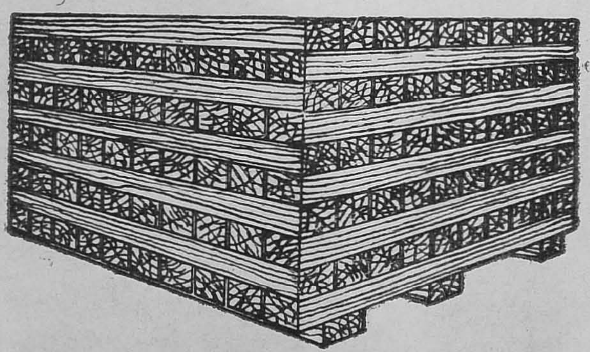

Fig. XIV—4. 'Close-crib' method.

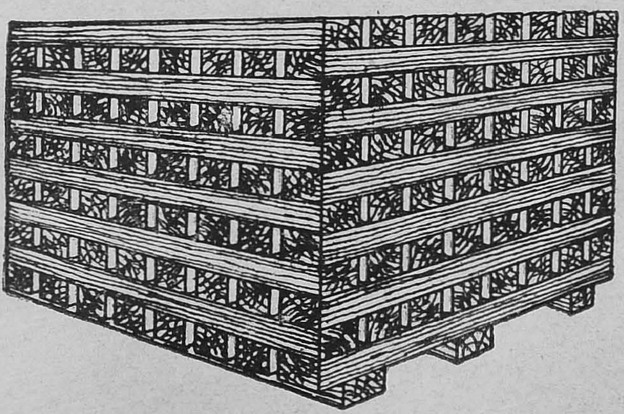

Fig. XIV—5. 'Open-crib' method.

part to another. If the yard is big enough, trolley lines should be provided to facilitate movement of timber. To protect the stacks from the direct sun, there should be some big shady trees in the yard.

Foundation.—The air entering an air-seasoning stack is cooled down and picks up moisture from the timber. As a result thereof, it becomes heavier and drains down through the vertical openings in the stack to its bottom. To avoid this cold and humid air stagnating in the bottom layers the stack should be built on raised foundations. Vertical pillars of treated timber or concrete on sufficiently firm floor, to support the stack, are an integral part of the foundation. They should be 30 cm square in cross section and 30 to 45 cm in height, and should be placed about one to two metres apart, along the length and width of the stacking unit. The length of the unit and spacing of the pillars would depend upon the length and weight of the material to be stacked. The foundation must be strong enough to bear the maximum load of the stack and sufficiently durable.

Long scantlings of suitable cross sections, say 10 cm× 10 cm and above, should be placed above the foundation pillars to serve as a framework for the stacking of timber. These foundation scantlings should be prepared from strong timbers which should be treated with a suitable wood preservative.

Vertical stacking (Fig. XIV-6).—This method of stacking timber is used mainly for the rapid surface drying of certain species of non-refractory woods, which are liable to develop mould and discoloration soon after conversion unless the surface moisture is removed rapidly to prevent the germination and growth of wood-staining mould and fungi.

The following precautions should be taken in the seasoning of wood stacked vertically :

(a) The planks stacked for seasoning should be turned frequently at least twice a day, so as to expose both faces to the sun alternately, otherwise there is a possibility of the planks becoming warped on account of one face drying faster than the other.

(b) The lower end of the planks should rest on some waste but sound wood, to prevent fungus and insect damage to the timber from contact with the earth.

After the surface of the timber becomes partly dry, it can be stacked by the horizontal method for further drying or it can be left standing in a vertical position till the completion of its drying, depending upon the species of timber and the climatic conditions of the locality. Timbers, which are liable to warp or distortion, may be stacked horizontally for further drying after vertical stacking.

Air-seasoning sheds.—With the strong tropical sun and the extreme seasonal fluctuations in climate, stacking in the open is generally not feasible in India. Air-seasoning sheds are necessary where sizeable quantities of timber have to be air-seasoned regularly. These are also essential for air-seasoning of costly timber in the form of half-wroughts for shoe lasts, rifle furniture, shuttles, bobbins, tool handles, etc. These sheds provide not only protection to the timber against the direct sun but also a certain measure of control on the drying rate of timber by regulating air circulation through the stacks.

Air-seasoning sheds are generally long buildings provided with raised foundation pillars for stacking the timber. A proper orientation lengthwise, from the point of view of direction of the sun under Indian conditions, is east to west. Other general requirements are a light roof raised to a sufficient height above the top of the stacks, proper ventilation to get rid of the evaporated moisture and to admit fresh air, and a well-drained *pucca* floor, suitably raised above the level of the surrounding ground to prevent seepage of soil moisture.

The sheds can be built out of a variety of constructional materials. The choice of material depends upon the permanency of the project, the economy of construction, local availability, etc. Brick walls with a corrugated galvanized iron sheet roof, raised about 6 metre high (to minimise radiation from the hot roof to the top of the stacks in the hot summer) are commonly used. Cheaper construction is possible by building mud walls reinforced with bamboo and plastered with lime, gammexane being added to the mud and lime for preventing biological deterioration. Roof can also be made of treated wooden shingles, supported on pillars and trusses made of durable or preservative-treated timbers,

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The design of a shed depends upon the climatic conditions of the place and the nature of the species to be air-seasoned. Three designs of sheds are recommended (Fig. XIV-7):

(i) *Shed type* 1.—This consists of a roof with walls on all four sides. Adjustable shutters should be provided near the roof and at the ground level in the two side walls to control ventilation. The shed may have a central passage, provided with trolley lines for loading and unloading of timber, running from one gate to another in the end walls, or alternatively a removable or sliding side wall is provided for the stacking of timber from the side. This type of shed is suitable for seasoning and storage of refractory hardwoods in hot and dry climates, such as laurel (*Terminalia tomentosa*), axlewood (*Anogeissus latifolia*), etc., in North India.

(ii) *Shed type* 2.—This type consists of roof with walls on three sides, north side being open. This is suitable for drying moderately refractory timbers like teak (*Tectona grandis*), rosewood (*Dalbergia latifolia*), sissoo (*Dalbergia sissoo*), toon (*Cedrela toona*), poon (*Calophyllum* spp.), benteak (*Lagerstroemia lanceolata*), etc., practically all over India except in the very moist climate.

(iii) *Shed type* 3.—This consists of a roof supported on pillars, all sides being open. This is suitable for drying moderately refractory timbers in very moist climate, and non-refractory timbers like mango (*Mangifera indica*), chir (*Pinus roxburghii*), semul (*Bombax ceiba*), gutel (*Trewia nudiflora*), etc., in hot and dry climate.

Wherever necessary, the open sides of shed types 2 and 3 should be provided with sufficient overhang of the roof to protect the stacks from the direct sun.

A 24m×12 m shed, accommodating double rows of stacks and provided with trolley tracks for loading and unloading of timber, will have an average stacking capacity of about 200 tonnes for timber 2.5 to 10 cm in thickness.

End-coating compositions.—In drying, moisture moves much more rapidly along the grain direction than across the grain. The ends of green timber, therefore, dry rapidly through the end-grain surfaces in advance of the portions farther away from the end, which can dry only slowly by movement of moisture across the grain through the lateral faces. The ends of timber are, therefore, more susceptible to cracking and splitting. All timbers are liable to end-splitting to varying extents, particularly under rapid drying conditions. End-splitting results in considerable wastage in logs as well as sawn timber, because the splits tend to extend to the sound surfaces as the timber dries.

End coating or paints are applied to the end surfaces of green timber or logs, soon after conversion or felling, to prevent too rapid drying and end-splitting. These can be economically used on logs, thick sections of timber intended for further conversion, squares, scantlings, planks (half-wroughts) of timber for special requirements and even for planks in the case of costly woods. The various compositions used are given below :

1. Hardened and filled gloss oil paint, manufactured and sold by M/s. Shalimar Paints (Private) Ltd., 6-Lyons Range, Calcutta. This can be applied with a brush; 4.5 litres (1 Imperial gallon) suffice for end-coating about 11.0—14.0 sq m (120 to 140 sq ft) of wood surface.

2. Anti-splitting-cum-preservative composition developed at the Forest Research Institute, Dehra Dun consisting of the following ingredients :

(i) High softening point Bitumin Mex. R 115/15	...	37.5% (by weight)
(ii) Low softening point Bitumin Mex. 10/20	...	12.5%
(iii) Creosote-fuel oil (50 : 50)	...	5%
(iv) Soapstone	...	30%
(v) Cinder (Boiler ash)	...	15%

This has to be melted and applied hot. The cost of treatment is estimated at about Rs. 34 per 100 sq m.

3. Bituminous paints.

4. Thick coal-tar.

5. Rosin and lamp-black (10:1), melted and applied hot.

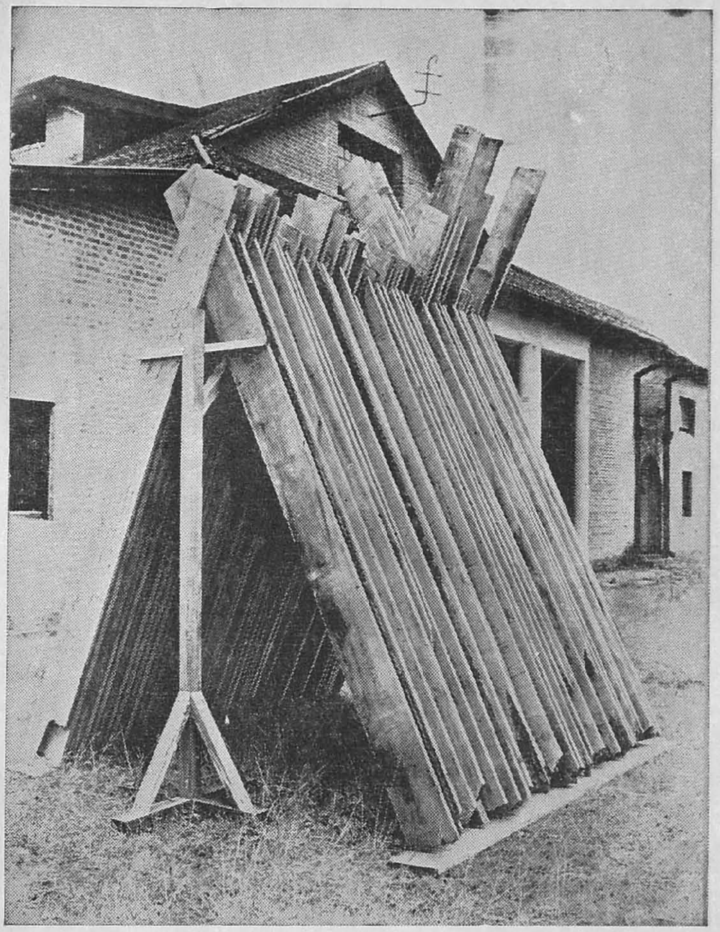

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Fig. XIV—6. Vertical Stacking.

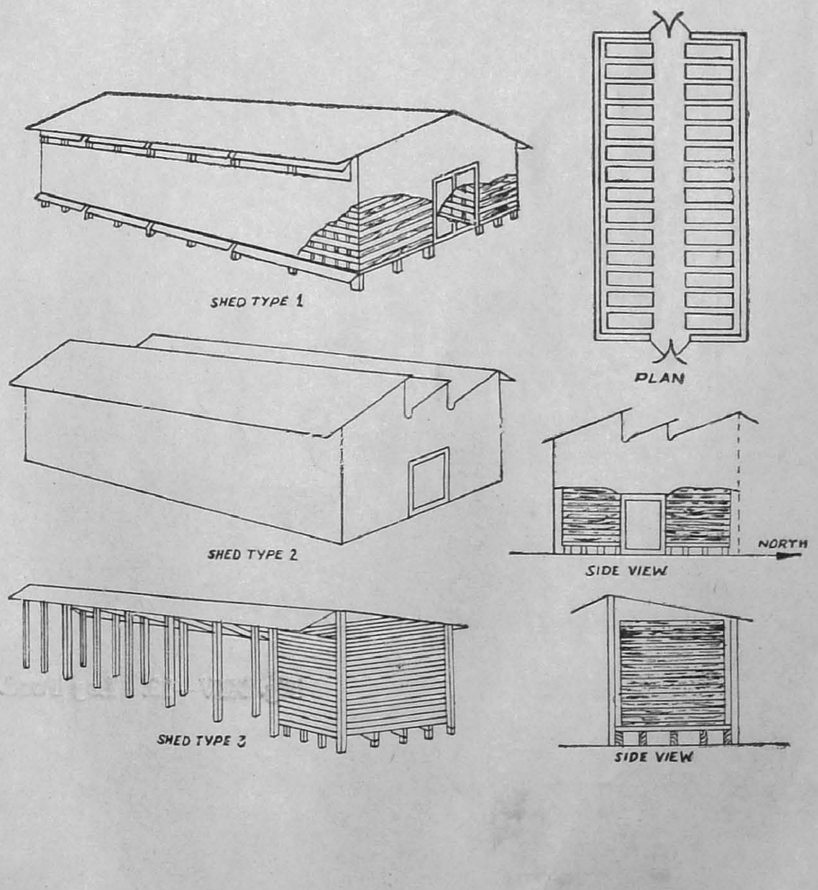

Fig. XIV—7. Air-seasoning sheds.

Fig. XIV—13. Log Pond.

6. Paraffin wax.

7. Molasses and lime (3 : 1).

For logs, sleepers and squares thick coal-tar is most widely used and is quite satisfactory. The composition developed at the Forest Research Institute is also reasonably cheap.

For air-seasoning of half-wroughts all the above compositions can be used. Out of these, gloss oil paint and paraffin wax are quickly applied and do not need to be removed before turning operations on machines. The rosin and lamp-black composition is brittle and the coated timber needs care in handling. Gloss oil paint, the composition developed at the Forest Research Institute, and rosin and lamp-black can be used at higher temperatures in kiln seasoning work also.

Appropriate season for conversion and stacking of timber for air-seasoning and period necessary for complete air-seasoning of various timbers

The period of conversion of logs in any sawmill is governed by the supplies of available timbers, and the demands of sawn timber, etc. However, highly refractory woods should preferably be converted for air seasoning towards the end of the rainy season, so that the timber passes through fairly mild climatic conditions in the early stages of its drying. This helps to prevent cracking and splitting in such timbers. The most suitable time for conversion of moderately refractory timbers for air-seasoning is during or towards the end of winter, i.e., the months of February and March. The timber will then season with moderate rapidity and will be ready for use before the rainy season. Non-refractory timbers, which are liable to mould attack and discoloration (sapstain), give the best results when converted for air drying during the hot dry season.

The period required for complete air-seasoning depends upon the species, the width and thickness of the material, the climatic conditions of the locality and the time of the year when seasoning is started. Generally speaking, 2.5-cm, thick planks of highly refractory woods take about 6 months, and 5-cm-thick planks about 1 year to air-season in a climatelike that of Dehra Dun. 2.5-cm-thick planks of moderately refractory hardwoods dry in about 4 months, while thicker sections upto 7.5 cm × 10 cm take 6 months to one year. 2.5-cm-thick planks of non-refractory woods take about two months to season. Railway sleepers and poles need 6 months to 1 year to achieve a degree of seasoning required for effective preservative treatment. Railway sleepers of an abnormally slow drying species like sal have been found to take two years to dry from green condition to an average moisture content of 20%.

Care for thick sections of timber.—Timber in its finished form, even in thick sections, should not be put to use straightaway in green condition. Certain amount of drying has to be effected beforehand in order to prevent degrade, whichis otherwise likely to occur due to subsequent uncontrolled drying during actual use. In certain cases this drying is also necessary to facilitate preservative treatment, and also to obtain the necessary mechanical strength. This drying is generally accomplished by storing the timber in a suitable manner. This process for thicker sections being rather prolonged is usually hampered by exigencies of prompt transportation, extra expenditure involved in handling and sometimes due to the urgent demand for the timber. But in view of the fact that rejection of timber of thick sections due to drying defects may be very high, and in certain cases these defects may render the timber totally useless, it always pays to foresee the demand and store in advance according to the methods already described. Whenever it is not possible to stack timber for air-seasoning immediately, but at the same time it is necessary to protect it against cracking and decay due to fungal and insect attack, the simplest way is to pile it systematically in closed stack, preferably under cover, after giving proper prophylatic preservative treatment. Period of such storage should not be prolonged unduly and the timber should be stacked for air drying at the first opportunity.

Kiln-Seasoning

The process of kiln-seasoning consists primarily in drying wood by the use of artificial heat. In the process, artificial control of relative humidity and air circulation are also provided to suit conditions at various stages of drying of the timber to achieve efficient drying. For this purpose the timber is stacked in chambers, called 'seasoning-kilns', which are fitted with equipment for

manipulation and control of temperature and relative humidity of the drying air and its circulation through the timber stack.

In air seasoning, the rate of drying depends largely on the weather conditions. It may be very rapid in the dry summer months—in fact, too rapid for many Indians hardwoods which are liable to cracking and splitting—and too slow during the cold winter months. It may be very much reduced, if stackings is done at the onset of the humid monsoon season. Very little control is thus possible on the drying process, and hence on the quality and period of drying, in the air-seasoing method. It is also impossible to attain low moisture contents in air seasoned stock in localities which keep very humid all the year round.

Kiln-seasoning provides a means of overcoming the limitation imposed by the vegaries of weather. Basically, the process of kiln-seasoning does not differ from air-seasoning. In both cases, unsaturated air is used as the drying medium and the principle of drying is the same, i.e., removal of moisture from the interior to the surfare of timber by diffusion under the moisture gradient set up for duing drying. and evaporation of this moisture from the surface of timber. However, the distinctive feature of kiln-seasoning is that drying is practicable at a faster rate than in air-seasoning without resulting in inrcased degrade. This is obtained by the accelerated rate of diffusion of moisture from the interior to the surface as a result of incrased temperature of the timber. There is flexibility of control over relative humidity conditions, and also a more positive air circulation than obtains under air-seasoning This allows the drying rate to be controlled during those stages in drying which are known to be critical for the development of various seasoning defects.

The great viroteus of kiln-seasoning are its rapidity adaptability and precision. The temperature employed inhibit, and are often also fatal to, insects and fungi, so that sterilization (at least partial) is achieved simultaneously with seasoning. Kiln-season enables wood to be dried to any moisture content regardless of weather conditions. It is certainly more adaptable to large-scale seasoning opeations than air-seasoning.

Design of seasontng-kilns.—Seasoning-kilns differ widely in tehir construction, equipment and design.

Constructional materlals.—The kiln chambers are generally built of brick masonry. Hollow cement-concrete slabs or hollow tiles are sometimes used in place of bricks to reduce heat losses from the kiln. Sheet metal in a double-walled construction with sandwiched thermal insulation, such as glass wood or asbestos, is also used in some modern kilns. Corrosion is completely avoided by using all-welded aluminium sheet construction for the interior wall. Very efficient design is called for to prevent moisture seeping into and deteriorating the sandwiched insulation, if a jointed construction is adopted instead. The metal construction enables prefabrication of chamber components and reduced installation time. If properly designed, it may also enable kiln-heat losses to be minimised. Pre-fabricated metal chambers are now being manufactured in India. However, the brick masonry chamber, with lime and mortar plaster on the inside and painted with moisture-retardant composition, is used most widely and has been found quite satisfactory.

Mode of heating.—Heating in kilns is carried out in several ways. Fuel gases from a furnace fired by oil or wood waste have been used satisfactorily in indirect-heating arrangement. Wood waste offers a cheap source of heat, specially in wood-working establishments or sawmills. Electrical heating can be used but has not been extensively adopted on account of the generally high cost of power. Steam-heating has been most extensively used in seasoning-kilns all over the world. Saturated steam is required for steam-heated. kilns. Pressures up to 5.6 kg per sq. cm. are desirable, but even low pressure exhaust steam from steam engines can be used by providing an increased radiating surface of heating coils.

Humidification.—Limited control of relative humidity inside a kiln is possible by adjusting the air inlets and outlets so as to retain in the kiln some of the moisture evaporated from the green wood. This, however, does not suffice to produce very high relative humidities as required while seasoning green timbers of refractory species liable to checking and splitting.

Both the furnace and the electric heating systems need some additional arrangement for raising the steam or vapour required for humidifying the air in the kiln. In some electrically heated kilns, low pressure steam for humidification is raised in a water vessel attached with the kiln by dipping resistance heating elements enclosed in tubes of alloy metal or by electrode heating. Water sprays injected into the hot kiln air, or impinged upon ducts (the latter being used in some furnace heated kilns), can also be used to raise the humidity of the air. In steam heated kilns, the design is simpler in this respect, as steam can serve the dual purpose of heating and humidification.

Air circulation system.—According to the mechanism employed for including circulation of the kiln air, the following types of seasoning may be mentioned :

(i) *Forced circulation kilns.*—In these the air is circulated by means of fans or blowers, which may be installed outside the kiln chamber (external blower kiln) or inside it (internal fan kiln). The design of the external blower kiln is more cumbersome and expensive as the blower has to be connected to the kiln chamber by air-tight inlet and return air-ducts, and a great ingenuity of design is called for to ensure uniform distribution of air in the stack The internally located fans (driven by motors usually situated outside the kiln) are simpler in design and can be more easily made to provide positive and uniform air circulation. The internal location of fans in the kiln may be above, below or on the side of the stack. The internal fan kilns are more common than the external blower type.

(ii) *Thermal or natural circulation kilns.*—In these kilns, the air circulation is obtained by thermal means (convection currents), i.e., by the natural process of hot air rising and cool air descending, and the heating pipes or elements are located below the stack. In one type, fresh air enters the kiln through a duct located below the heating pipes and gets heated up, rises through the stack drying the timber enroute, and is ejected through chimneys located in the roof of the kiln. In the second type the rising hot air, which gets cooled while picking up moisture from the timber stack is allowed to descend along the sides of the stack. It is then heated up again and re-circulated.

The speed of air through the stack, in either type of the above thermal circulation kilns, is only about 15 cm per second. Further, it is also difficult to achieve positive and uniform circulation. On the other hand, air speeds are much higher in forced circulation kilns, ranging from 60 cm per second in conventional designs to as high as 4.9 m per second in some modern designs. Under identical drying conditions of temperature and humidity, drying generally gets faster as the circulation speed increases. Thus, timber generally requires about 50 per cent longer time to dry in thermal circulation than in forced circulation kilns of the conventional type. But there is an optimum circulation speed above which further increase does not improve operational efficiency. Also, the advantage of using very high air speed is likely to be limited in case of refractory hardwoods which part with their moisture only very slowly, and hence forcing the pace of drying beyond a certain limit is likely to result in rapid surface drying and excessive cracking and splitting.

Classification of kiln designs according to their operation

Apart from the differences in constructional materials, modes of heating and humidification and air circulation system, seasoning kilns are classified into the following two broad types, according to their construction and operation :

1. *Progressive kilns.*—These kilns are usually a long tunnels in which the progressive drying conditions of the schedule are controlled along the length. A continuous supply of timber stacked on trucks (trolleys) is moved at a suitable predetermined rate from one end to the other, the air at the loading end being relatively cool and moist and at the unloading end warm and dry. During the movement of each stack (truck) of timber, it is held for the required period under each set of progressively drastic conditions maintained along the tunnel till the stack becomes dry at the unloading end. These kilns can be worked only where considerable quantities of timber of the same species and uniform thickness and moisture content are handled. These conditions are seldom found in practice in this country.

2. *Compartment kilns.*—In these kilns the timber remains stationary. The drying conditions are uniform within the kiln but are successively varied from time to time in accordance with the schedule, as the timber dries. Such kilns provide a more flexible control over the entire charge of timber being seasoned, and are better suited to the needs of timber firms which have to season timbers of varied

species and thicknesses, including refractory hardwoods sensitive to checking and splitting. These are more widely used than the progressive kilns in India, as also in other countries.

Kiln control.—The control of temperature and relative humidity in steam heated kilns can be effected automatically by providing kiln-controller equipment. The use of automatic control in kiln operation, is, however, not indispensable. Manual control by trained kiln operators is satisfactorily possible and is practised quite widely.

Kiln-drying schedules.—The kiln-drying schedule lays down an optimum set of drying conditions—temperatures and relative humidities to be maintained in kiln for satisfactory and efficient drying of timber. The temperatures and relative humidities applied at any given stage during the course of drying have a direct bearing on the course of development of moisture gradient, drying stresses, and hence seasoning defects in the further drying of timber. Theoretically, there is an optimum set of temperature and relative humidity conditions to be progressiely maintained at various stages during drying, whereby drying can proceed at a consistently rapid rate without, however, permitting the drying stresses to exceed dangerous limits.

In general, comparatively low temperature and high relative humidity are maintained at the outset. This is the stage when the timber is in a fresh sawn green condition; the moisture gradient and drying stresses are critical at this stage for the development of surface-cracks and end-cracks, and for the initiation of case-hardening, which in subsequent stages may result in honey-combing. As the drying progresses, the temperature can be gradually raised and the relative humidity lowered. This intermediate stage is critical for the development of honey-combing and warping, and needs control of temperature within the limits that timber will tolerate. As seasoning nears completion, temperatures can be maintained fairly high and the humidity considerably low. The limit to the temperature is set by the consideration that the timber should retain its strength; the timber is believed to suffer permanent deterioration when subjected to an excessively high temperature. In the final stages of drying, an equalization of the surface and core-moisture contents and of the moisture contents of different boards is attempted. This is finished off with a conditioning treatment to relieve residual case-hardening stresses in the crosssection.

Generally two types of kiln-drying schedules are used in commercial practice. They are : (i) moisture-content-based schedules, in which the successive changes in seasoning conditions are guided by the moisture content attained by imber in the course of seasoning, and (ii) time schedules, in which successive sets of conditions are maintained for pre-determined periods until the timber is supposedly dry. Time schedules are practicable and efficient only where timber charges of more or less uniform quality, thickness and mois ture content are kiln-seasoned. They are not perfectly safe to use for sensitive hardwoods susceptible to excessive cracking and splitting in seasoning. Moisture-content-based schedules are recommended for Indian conditions, where a large number of refractory hardwoods have to be handled and untilformity in the material being processed is also not usual in practice. Such drying schedules have been worked out for about 150 species of commercially important Indian timbers.

Seven schedules, numbered as I, II, III, IV, V, VI and VII (Table XIV-2; also refer to Table XIV-1), have been standardized for Indian timbers. Each schedule contains five to nine stages, each stage being distinguished by specified dry and wet bulb temperatures and relative humidity with reference to the moisture content of the wood at the commencement of that stage.

The schedules differ for different species. For example, for those timbers which are liable to a cracking and splitting during drying, such as *Acacia nilotic*, (babul), a low temperature, say 40°C to 45°C, and a high relative humidity, say 85 per cent, is maintained in the beginning, and the drying conditions are intensified gradually. The charge is usually steamed at a temperature of 55°C (the relative humidity being 100 per cent) before starting the drying operation. This is done for heating up the charge and for moistening the surface layers of wood. Light soft timbers used for packing-cases, such as *Tetrameles mudiflora, Trewia nudiflora, Hymenodictyon excelsum*, etc., require rapid surface drying to start with, in order to prevent the growth of mould and stain, and must be kiln-dried at a fairly high temperature, say 55°C, and at a low humidity, say 50 percent, at the beginning of the seasoning operation. The drying conditions are then quickly intensified to 65°C temperature and 30 per cent R. H. after about 30 hours if, for example, 1.3 cm thick boards are being dried.

Sterilization of timber against mould growth, sapstain fungi and insects can also be carried out in a kiln by giving high humidity treatment at appropriate high temperatures.

TABLE XIV-2

Schedules I to VII recommended for the seasoning of Indian Timbers

(Source : Code of Practice for Seasoning of Timber, IS : 1141-1958, New Delhi, 1958)

Schedule I

Woods for packing-case manufacture, as marked 'I' in Table XIV-1, are covered by this tentative schedule.

SCHEDULE I, FOR 2.5 CM THICK PLANKS

Moisture content of the wettest timber on air-inlet side	Temperature Dry bulb °C	Wet bulb °C	Relative humidity per cent
Green	52	44	62
60%	55	45	55
40%	60	46	44
30%	65	48	39
20%	68	48	33.5

These timbers will take about 4 to 5 days to season. Initial steaming of the charge for about 2 hours at 55°C and 100 per cent relative humidity should be carried out to kill mould growth.

Schedule II

Timbers commonly used for cheap planking or for moderately-heavy type of packing-cases, as marked 'II' in Table XIV-1, are covered by this tentative schedule.

SCHEDULE II, FOR 2.5 CM THICK PLANKS

Moisture content of the wettest timber on air-inlet side	Temperature Dry bulb °C	Wet bulb °C	Relative humidity per cent
Green	45	40	72
60%	47	40	64
40%	49	40	56
30%	53	40	44
20%	58	40	32.5

These timbers will take about 5 to 7 days tu season. Initial steaming of the charge fyr about 2 hours at 55° C at 100 per cent relative humidity should be carried out to kili mould groath.

Schedule III

Most of the light furniture woods, as marked 'III' in Table XIV-1, are covered by this tentative schedule.

SCHEDULE III, FOR 2.5 CM THICK PLANKS

Moisture content of the wettest timber on air-inlet side	*Temperature* Dry bulb °C	Wet bulb °C	Relative humidity per cent
Green	42	38	76
60%	45	40	72
40%	47	40	64
35%	49	40	56
30%	51	40	50
25%	53	40	44
20%	55	40	39

These timbers will take about 8 to 10 days to season. In addition to the initial steaming, one intermediate steaming and one steaming towards the end for 2 to 3 hours at 55°C and 100 per cent relative humidity would be required.

Schedule IV

Most of the furniture woods, as marked 'IV' in Table XIV-1, are covered by this tentative schedule.

SCHEDULE IV, FOR 2.5 CM THICK PLANKS

Moisture content of the wettest timber on air-inlet side	*Temperature* Dry bulb °C	Wet bulb °C	Relative humidity per cent
Green	42	38.5	80
60%	42	38	76
40%	45	40	72
35%	47	40	64
30%	49	40	56
25%	52	40	47
20%	55	40	39

These timbers will take 12 to 15 days to season. One intermediate steaming and one steaming towards the end of drying at 55°C and 100 per cent relative humidity for about 2 to 4 hours would be required. For precision drying for high class work, conditioning treatment should be given.

Schedule V

Timbers used for furniture, constructional work or for certain special items such as bobbins and other turnery articles, as marked 'V' in Table XIV-1, are convered by this tentative schedule.

SCHEDULE V, FOR 2.5 CM THICK PLANKS

Moisture content of the wettest timber on air-inlet side	*Temperature* Dry bulb °C	Wet bulb °C	Relative humidity per cent
Green	42	38.5	80
45%	45	40	72
35%	46	40	68
30%	48	40	60
25%	50	40	53
20%	52	40	47
15%	55	40	39

These timbers will take about 13 to 16 days to season. In addition to the initial steaming, two intermediate and one final steaming at 55° C and 100 per cent relative humidity for 2 to 4 hours would be required for these timbers.

Schedule VI

Heavy planking timbers, most of which are also used for structural purposes, as marked 'VI' in Table XIV-1, are covered by this tentative schedule.

SCHEDULE VI, FOR 2.5 CM THICK PLANKS

Moisture content of the wettest timber on air-inlet side	Temperature Dry bulb °C	Temperature Wet bulb °C	Relative humidity per cent
Green	40	37	82
60%	42	38	76
40%	45	40	72
35%	46	40	68
30%	47	40	64
25%	48	40	60
20%	50	40	53
18%	52	40	47
15%	55	40	39

These timbers will take about 16 to 20 days to season. They need slow and careful drying. The charge will have to be steamed at least twice during the course of drying in addition to the initial and final steamings at 55°C and 100 per cent relative humidity for 2 to 4 hours.

Schedule VII

Some highly refractory timbers, as marked 'VII' in Table XIV-I, are covered by this schedule.

SCHEDULE VII, FOR 2.5 CM THICK PLANKS

Moisture content of the wettest timber on air-inlet side	Temperature Dry bulb °C	Temperature Wet bulb °C	Relative humidity per cent
Green	40	38	88
60%	41	38	82
40%	42	38	76
35%	45	40	72
30%	46	40	68
25%	47	40	64
20%	50	42	61
18%	52	42	54
15%	55	42	45

These timbers will take about 24 to 30 days to dry. The charge will need at least three intermediate steaming operations in addition to initial and final steamings at 55°C and 100 per cent relative humidity for 2 to 4 hours.

Control of final moisture content and removal of residual stresses in timber in kiln-seasoning

When operating a kiln, temperature and relative humidity changes are to be based on the moisture-content values of kiln samples, the samples being so chosen as are representative of the wettest boards in the entire kiln. The kiln samples are periodically removed from the kiln, reweighed and the moisture content calculated, after which they are replaced in the kiln. Method of cutting initial moisture content

sections and kiln samples from timber to be kiln dried is illustrated in Fig. XIV-8(a). Changes in the temperature and relative humidity are made as indicated in the schedule being followed.

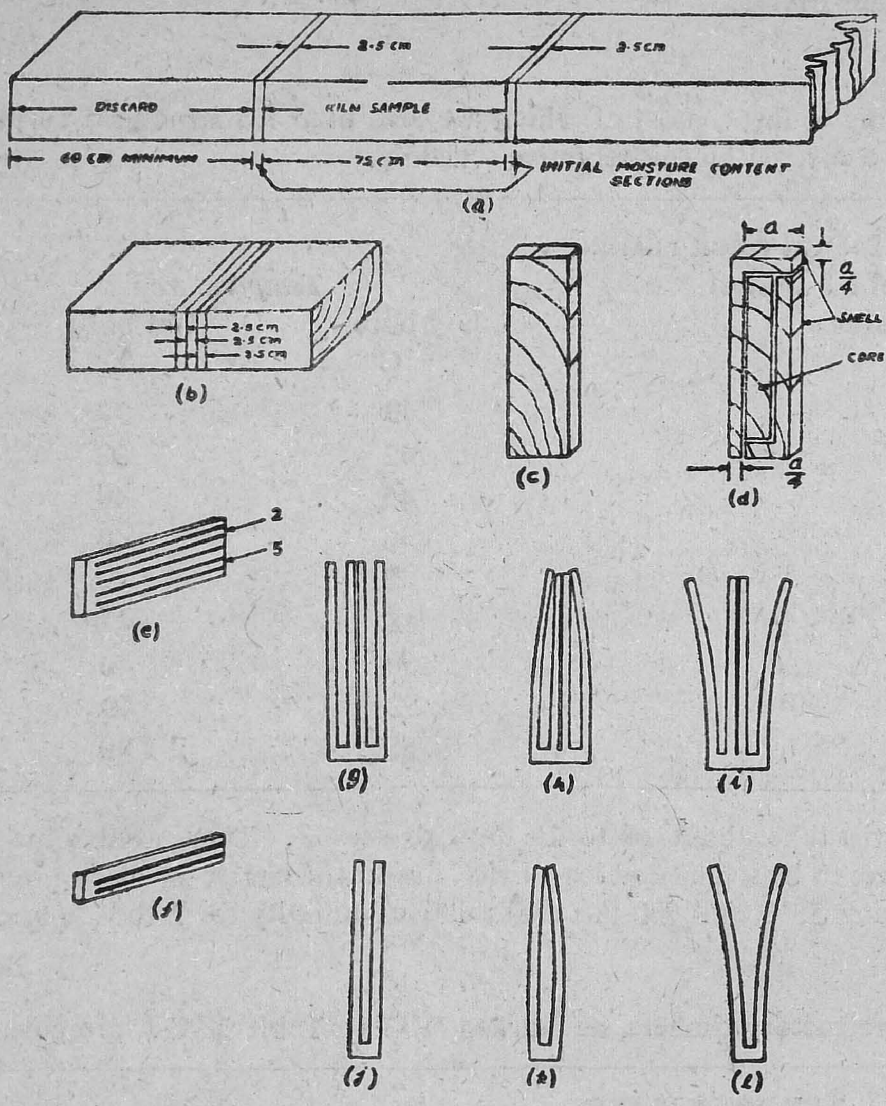

Fig. XIV—8. Methods of making kiln samples; moisture distribution and case-hardening tests.

(a) Method of cutting initial moisture content sections and kiln samples
(b) Method of cutting final moisture content and case-hardening sections after kiln drying
(c) Final moisture section (d) Final moisture distribution section (e) Sowing of case-hardening sections, 4 cm and above thick (f) Sawing of case-hardening sections, less than 4 cm thick
(g) and (j) No case-hardening
(h) and (k) Severe case-hardening
(i) and (l) Severe reverse case-hardening

Towards the end of drying, it is a desirable practice to determine the moisture distribution in the cross-section of the samples by cross-cutting section 2.5 cm thick along the grain, sawing it on the freshly cut section into slices representing the shell, intermediate and core portions, and determining the moisture contents of individual portions by oven-drying [Fig. XIV-8(b), (c) & (d)]. If moisture gradient in the section is found to be excessively high, it is equalized by prolonging the drying process after a proper re-adjustment of the drying conditions.

In kiln-drying timber, not only the final moisture content but also the stresses should be controlled. Such stresses originate from the moisture gradients set up within the board right from the initial stages of drying. Kiln-dried timber with pronounced residual internal stresses is usually referred to as being *case-hardened.* In such timber, the outside layer is in compression and the core is in tension. When such a piece is resawn (parallel to the wide surface of the board), the layers under tension will become shorter and those under compression (outside) will elongate, resulting in cupping of the pieces.

A case-hardening test, therefore, usually has to be made in the final stages. For this a section, 2.5 cm thick, is cut along the grain from the plank. The test section is finally slotted out into prongs with a saw. Sections 4 cm and above in thickness are sawn into six equal thickness prongs as in Fig.

XIV-8(e), prongs 2 and 5 being broken out for case-hardening test; whereas sections less than 4 cm thick are sawn into only three prongs of equal thickness, the centre one being removed for the test [Fig. XIV-8 (f)]. The prongs of the test section will attain curvature, as in Fig. XIV-8(g) to (l), under different conditions of case-hardening. The prongs should be room-dried for about 24 hours and the room-dried condition observed for arriving at conclusions regarding case-hardening.

Since moisture distribution in the section plays an important part in the behaviour of its prongs, the real test for case-hardening can be made only after the moisture content factor is eliminated by drying the case-hardening section to a uniform moisture content.

Case-hardening can be relieved by subjecting the timber to a final steaming treatment at the end of drying, at the conditions indicated under the Schedules given in Table XIV-2. Steam spray is let in until the air becomes saturated. The steaming is continued for an adequate period so that the outside layers absorb sufficient moisture to relieve the stress. There is always the risk of 'over-steaming'. When this happens, 'reverse case-hardening' will occur and the timber will cup and warp when reswan, in the direction opposite to that of case-hardened stock.

Seasoning-kilns suitable for drying Indian woods

A brief description of some of the different types of kilns suitable for use in India, which have been tested, and in some cases designed, at the Forest Research Institute, Dehra Dun, is given below :

(a) *Steam heated, overhead internal fan reversible air circulation seasoning-kiln* (Fig. XIV-9).—This type of kiln gives very satisfactory results with almost all kinds of woods, including hardwoods for the manufacture of furniture, railway carriages, ship building, shuttles, bobbings, picker arms, tool handles and helves, as well as the lighter soft timbers for box-shooks and similar work. This kiln can also be useful for drying veneers and conditions plywood as well. Any desired conditions of temperature within reasonable limits and humidity up to 100% can be maintained in the drying chamber. The circulation of air is good and uniform throughout the whole kiln, which results in the uniform drying of timber in different parts of the stack.

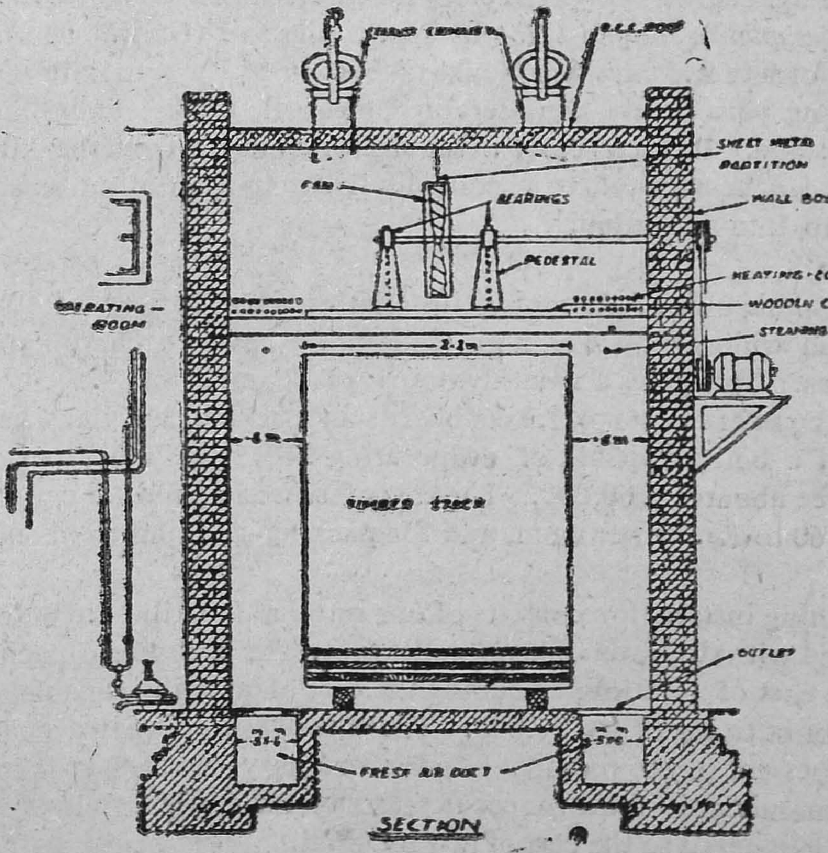

Fig. XIV—9. Internal fan reversible air circulation steam heated kiln.

A standard size of this kiln consists of a chamber 20ft × 11ft × 15ft, i.e., 6.1 m × 3.35m × 4.6m (internal dimensions), in size and having a stacking capacity of about 14 cu m of 2.5 cm thick planks per charge. The kiln is partitioned (in height) by a horizontal false ceiling above which the fans and

heating equipment are installed. The timber is stacked below the false ceiling. Two coils of steam pipes for indirect heating of the kiln air and two single lengths of perforated pipes for injecting live steam for extra humidification are provided, one on eiher side of the stack above the false ceiling. Chimneys are provided in the roof for venting moist air, and air ducts at floor level to admit the required quantity of fresh air for use when drying light woods which give out a lot of moisture during the seasoning process. The heated and humidified air is circulated through the stack of timber at an approximate speed of 60 cm per second by means of three externally driven propeller fans. The circulation is reversible so that difference in the drying rates on the two sides of the stack is eliminated. The temperature and R.H. are manually controlled by adjusting the pressure and amount of steam admitted to the heated coil and the perforated pipe. A boiler for raising steam is required. Fans can be driven by diesel or steam engine where electric power is not available.

A maximum of about 270 kg of steam are required per hour for a standard size kiln chamber. The drying rate and the steam consumption are, however, faster when the timber is green but fall down appreciably near the end of drying. It is therefore possible to run two chambers of the above size simultaneously with a boiler of 360 kg of steam per hour capacity (i.e., only slightly higher than that required for a single chamber), if the loading is so arranged that when one chamber holds green timber the charge in the other is nearing end of drying. Slightly smaller boiler capacity than the above may do for kilns where only slow-drying refractory hardwoods are seasoned.

The output of seasoned material from a kiln varies considerably, depending upon the species and thickness of timber and whether the timber is kiln-seasoned green from the saw or after partial air seasoning. Generally light hardwoods, such as gutel (*Trewia nudiflora*), kanju (*Holoptelea integrifolia*), salai (*Boswellia serrata*), in packing case sizes take 2 to 4 days; moderately refractory furniture class of species like teak (*Tectona grandis*), sissoo (*Dalbergia sissoo*), siris (*Albizia* spp.), rosewood (*Dalbergia latifolia*), padauk (*Pterocarpus dalbergioides*), toon (*Cedrela toona*), poon (*Calophyllum* spp.), benteak (*Lagerstroemia lanceolata*), etc., in the form of 2.5 cm thick planks take about 10 days on an average; slow-drying refractory hardwoods, such as laurel (*Terminalia tomentosa*), bijasal (*Pterocarpus marsupium*), hopea (*Hopea* spp.), dhaman (*Grewia* spp.), sandan (*Ougeinia oojeinensis*), etc., in the form of 2.5 cm thick planks take 16 to 24 days to kiln-season from the green condition. The seasoning periods are considerably longer if thicker scantlings are kiln-seasoned directly from the green stage. In their case, a satisfactory output from the kiln can be maintained and kiln-seasoning cost can be reduced to enconomic limits by partial air-seasoning to about 25% moisture content prior to kiln-seasoning.

The minimum economic unit of seasoning installation is a battery of two drying chambers, each 6.1 m long, 3.35 m wide and 4.6 m high (internally) having a charging capacity of 14 cu m for 2.5 cu m thick planks. This gives a monthly output of 70 cu m of 2.5 cm seasoned boards of furniture woods, or 225 cu m of 1.3 cm to 1.9 cm boards of packing-case light hardwoods. The cost of erection, inclusive of a boiler capable of evaporating 360 kg of water per hour at 4.2 to 5.6 kg per square cm, will be about Rs. 60,000. The cost of seasoning for 2.5 cm thick planks of furniture woods will be Rs. 60 to Rs. 70 per cu m, and for packing-case timber about Rs. 18 per cu m.

A very small seasoning installation consists of one internal fan kiln, 4.6 m long, 2.7 m wide and 3.8 m high. It is provided with two reversible propeller fans. The charging capacity is 7 cu m of 2.5 m thick sawn timber. The cost of erection, including the cost of a boiler capable of giving 90 kg of steam per hour, will amount to about Rs. 20,000. The cost of seasoning in a small installation of this size is very high and it does not pay to put up a kiln for ordinary jobs such as furniture making. This can be worked as an economic unit if the timber is seasoned for costly articles, where the price of the finished goods is high as compared to the cost of raw material.

Designs of still bigger kilns are also available. A kiln 8.2 m long, 5.8m wide and 4.6 m high (for double stacking) fitted with eight fans has a charging capacity of 34 cu m of 2.5 cm thick planks. Another kiln 12.8 m long, 3.8 m wide and 5.3 m high, having seven fans and fitted for truck piling for seasoning large quantities of packing-case timbers (about 280 cu m per month), is also available.

For economic running of seasoning installations the following points should be borne in mind :

(i) Timbers of widely different degrees of refractoriness, thicknesses and moisture contents should not be mixed together in a single kiln charge.

(ii) The kiln should be run 3 shifts a day for most economic outturn. The period of drying increases by about 25% on the average when the kilns are run only 2 shifts a day. Running for less than 2 shifts is uneconomical.

(iii) The running of kilns should be entrusted to trained personnel to ensure minimum possible periods of drying consistent with quality of drying.

(iv) Partial air-seasoning can be adopted for reducing kiln-seasoning time for slow-drying and thick timbers, provided proper care is taken in air-seasoning.

(v) It is possible to cut down expenditure on fuel by partly using sawmill wood-waste in place of coal for firing the boiler.

(b) *Furnace kilns.*—A brief description of two types of Furnace Kilns and Hot-Air Kiln designed at the Forest Research Institute, Dehra Dun, is given below. Unlike steam heated kilns, all types of furnace kilns are not suitable for seasoning all kinds of woods. Usually a furnace kiln which is suitable for drying furniture woods is not suitable for the seasoning of light packing-case timbers. Furnace kilns however, have the advantage that they are generally cheaper to instal and more economical to work than steam heated kilns, but the drying is not so satisfactory as in the steam heated kilns.

(i) *The indirect-heated, internal-fan, furnace kiln* (Fig. XIV-10).—In this kiln the hot gases coming from a wood burning furnace pass through a set of sheet iron pipes fitted inside the drying chamber. The smoke gases escape into the atmosphere through a chimney outside the chamber after passing through the pipes. They do not come in direct contact with the wood to be dtied. The air of the kiln is heated indirectly, and is circulated by means of fans fitted inside the chamber, for which purpose motive power is required.

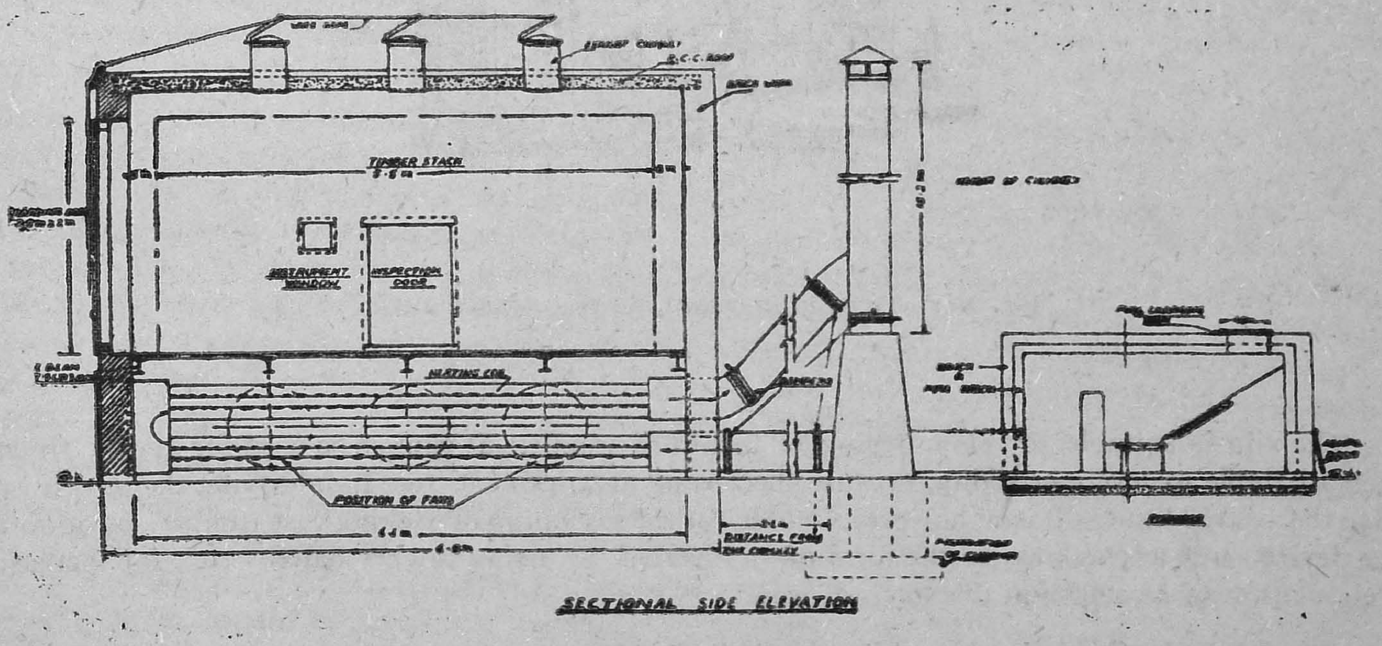

Fig. XIV—10. Indirect-heated, internal-fan, furnace kiln.

The kiln is suitable for the rapid seasoning of packing case timbers. It is not suitable for the seasoning of heavier hardwoods because there is no arrangement for humidifying the air in the kiln.

It has been found that 1.3 cm boards of timber like *Bombax ceiba* (semul) can be seasoned from the green condition to 10 per cent moisture content in about 36 hours in a kiln of this type.

A kiln having a charging capacity of 8.5 cu m of sawn material will give a monthly output of 70 cu m of seasoned box-shook material. The cost of drying will be about Rs. 14 per cu m, and it will be less than that for a stem-heated kiln. The cost of erection of the kiln would be about Rs. 10,000.

(ii) *The new F. R. I. furnace kiln* (*The indirect-heated, thermal-circulation, furnace kiln*).—In this type of kiln (Fig. XIV-11), the hot gases coming from a wood burning furnace pass through large radiating ducts made of sheet iron and fitted inside the drying chamber below the stack of timber to be seasoned. The air of the kiln becomes heated and rises through the stack of wood, after which it is allowed to escape through chimneys provided in the roof of the kiln to promote circulation of air. Fresh air inlets are laso provided for the same purpose.

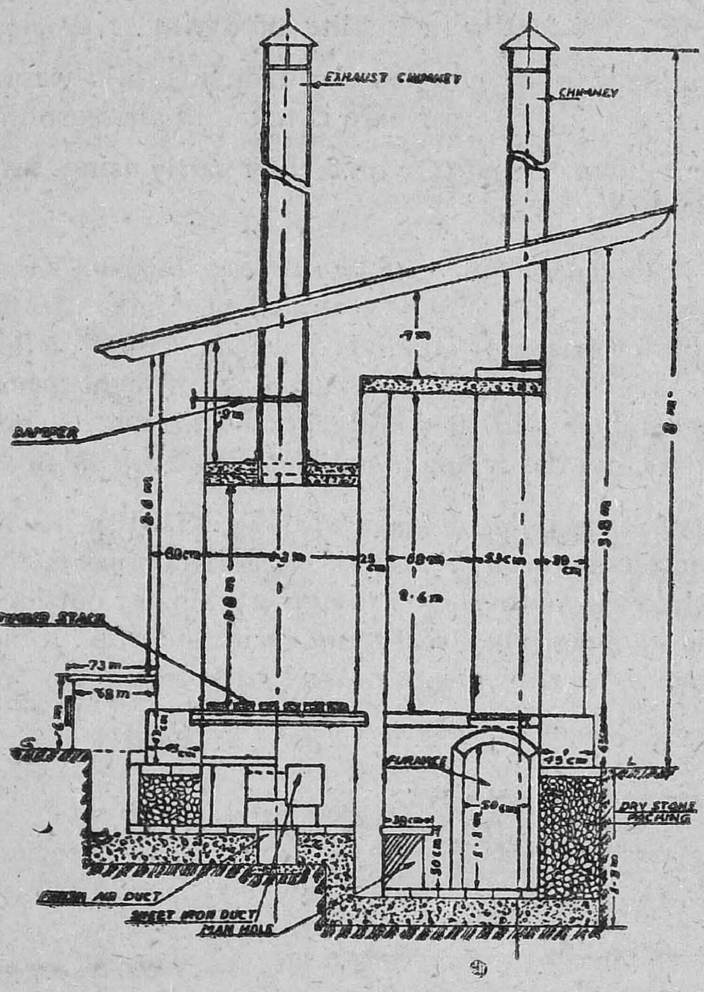

Fig. XIV—11. Indirect-heated, thermal-circulation kiln

The kiln is suitable for slow drying of furniture woods. It cannot be used for drying timbers which are liable to severe cracking, because there is no arrangement for humidifying the air in the kiln to the desired limit. It can, however, be used for the seasoning of packing-case timbers by adopting some device, such as stacking in the form of an inverted 'V', using thicker battens etc., for increasing the circulation of air through the stack of wood.

2.5 cm boards of a timber like *Adina cordifolia* (haldu) take about 15 days to dry in a kiln of this type, working the kiln 12 hours a day.

A kiln of this kind having a charging capacity of 5.6 cu m of sawn timber, gives two charges of seasoned furniture timber per month. The cost of drying will be about Rs. 25 per cu m for 2.5 cm thick boards. The kiln does not require a steam boiler or motive power for fans. The cost of erection of the kiln would be about Rs. 6,000.

(iii) *Hot-air kiln* (Fig. XIV-12)—This is an indirect-heated furnace type of kiln suitable for completing the seasoning of partially air-dried half-wroughts for the manufacture of shuttles, bobbins, picker arms, helves and tool handles. The kiln is a masonry chamber provided with a number of ducts

in the floor through which hot gases from a wood burning furnace are passed. The chamber is fitted with racks for holding the half-wroughts of wood to be seasoned. The air in the room gets heated by contact with the ducts in the floor, and rises upwards through the racks, drying the blanks *en route*.

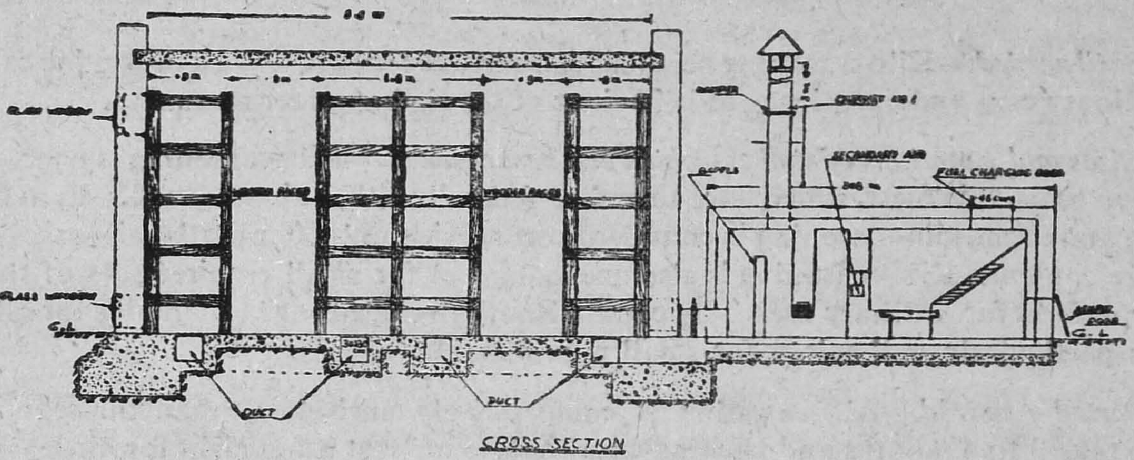

Fig. XIV—12 Hot-air kiln.

It is estimated that 6.3 cm × 6.3 cm blanks of refractory hardwoods, cut from planks which have been air-seasoned for about two months, can be completely seasoned in about 15 days in a hot-air kiln of this type. A small chamber capable of holding about 11 cu m of wood in one charge is considered to be a good economic unit. The cost of erection would amount to about Rs. 6,000. A kiln of this design can also be heated by means of steam if it is already available on the premises.

(c) *Veneer dryers.*—Green veneers can be air-seasoned or kiln-dried exactly like ordinary wood. For the quick seasoning of veneers, the usual method in Europe and America is to dry them in long progressive dryers. These dryers are closed metal chambers, about 15 m to 45 m long, usually fitted with powerful fans for the rapid circulation of air, and with steam-heated pipes for raising the temperature of the air circulating inside the dryer. The green veneers are fed into one end of the drying chamber, and these slowly move towards the other end by means of endless belts or between rollers fixed along the length of the dryer. Unfortunately progressive dryers are very costly.

Such dryers are, however, not essential for the quick seasoning of veneers, and it is possible to use certain other types of kilns which are much cheaper. The "internal fan, reversible circulation, steam heated, kiln" described above, can be successfully used for this purpose in plywood factories where steam is available. The advantage of this type of kiln is that it can be used both for the seasoning of boards as well as for veneers. 1.6 mm veneers of *Mangifera indica* (mango) can be seasoned in this kiln in about three hours. In order to save time in loading and unloading the chamber, the stacking of green veneers can be done on trolleys outside the skin. The loaded trucks can then be pushed into the drying chamber, which should preferably be provided with rails to facilitate the movement of trolleys. This type of kiln can also be used for the conditioning of plywood.

The Forest Research Institute, Dehra Dun has also designed a simple type of steam-heated tunnel dryer made of masonry, in which trolleys loaded with green veneers can be moved from one end of the dryer to the other. The veneers are dried by means of the hot air which is forced into the drying chamber by a powerful fan fitted outside the dryer. The cost of erection of a tunnel dryer, excluding the cost of a boiler, would be about Rs. 16,000.

In plywood factories where steam is not available, veneers can be dried in a furnace-heated veneer-drying kiln specially designed for this purpose.

KILN-SEASONING VS. AIR-SEASONING

Ordinarily, it is not possible to distinguish kiln-seasoned timber from air-seasoned timber by any test. If the moisture content condition attained is satisfactory and biological and mechanical defects (arising from drying stresses) have not occurred in the seasoned timber, the process adopted (whether air-or kiln-seasoning) is technically immaterial. In pratice, however, a choice has generally to be made

between these two processes, according to local conditions and the respective merits and limitations of each which are discussed below :

(i) *Initial investment.*—Kiln-seasoning generally calls for higher initial investment than air-seasoning.

(ii) *Skill needed.*—Kiln seasoning needs skilled supervision, whereas air-seasoning can be carried out with ordinary care and experience of behaviour of the timber under seasoning.

(iii) *Sizes and quantities of timbers which can be seasoned.*—Kiln-seasoning is uneconomical for sections above 10 cm thickness, which have therefore generally to be air-seasoned. Even for thickness between 5 cm and 10 cm, kiln-seasoning is considered economical only after partial air-seasoning to about 25% moisture content. Kiln-seasoning is also uneconomical for small requirements of timber (below 11 cu m per month) for ordinary uses. By comparison, air-seasoning is adaptable for all varieties of sizes and is particularly well suited for small requirements.

(iv) *Period required.*—Air-seasoning is comparatively much slower than kiln-seasoning. Furniture timbers take 3 to 4 months and packing case timbers at least a fortnight for air-seasoning in dry weather; longer period being required during the rains. However, kiln-seasoning can be completed within 10 to 12 days and 36 hours respectively. Capital is locked up in holding huge stocks of timber for longer periods in air-seasoning.

(v) *Yard space requirement.*—Air-seasoning requires huge yard space for comparable output of seasoned timber than kiln-seasoning. This is usually a drawback with air-seasoning in big cities where rents of land are very high.

(vi) *Quality of drying.*—Control of degrade (mechanical and biological defects) is often difficult in air-seasoning particularly when refractory timbers are seasoned in hot and dry climate or light packing-case timbers in vey humid climate. Production of defect-free timber, dried to a uniform moisture content, is often a very time-consuming process in air-seasoning. Moreover, low moisture contents, as are required for special jobs, are not possible to attain in very humid climates even after prolonged air-seasoning. Kiln-seasoning can give fully satisfactory results within much shorter periods.

Air-seasoning, if properly carried out with due attention to the period of conversion of timber, its protection from drastic climatic conditions, proper prophylactic preservative treatment wherever necessary, and the period required for complete and uniform seasoning, can yield seasoned timber of quality in no way inferior to that obtainable by kiln-seasoning. Air-seasoning is, however, usually satisfactory and practicable only for small requirements of seasoned timber. Both for regular requirements of large quantities of seasoned timber and for timber seasoned to precise moisture content tolerance, kiln-seasoning is better adapted than air-seasoning. Though kiln-seasoning is generally costlier than air-seasoning, it needs to be emphasized that at present, because of the high cost of land, particularly in big cities, and the high rate of interest on capital blocked up in holding stocks of timber, together with higher losses of timber through degrade in air-seasoning, the cost of air-seasoning is also quite appreciable. In the context of growing cost of primary species like teak, sissoo, etc., extra investment on kiln-seasoning of cheaper secondary species is economically quite feasible, considering that they can be used as satisfactory substitutes for primary species for ordinary purposes after proper processing.

Sizes of timber that can be seasoned

Round timber in the form of logs cannot be effectively and efficiently seasoned. Apart from the considerable losses that may occur in logs through cracking, splitting, insect and fungal attack, experience has shown that, even after years of storage in the open logs of some species may have nearly the same amount of moisture in their interior as they had when the trees were felled. It is, therefore, not economical to season timber in log form, unless it is required to be used as piles, poles, posts, etc., and as such it must be sawn into the ultimately required sizes of planks and scantlings allowing oversize for shrinkage and planing, before seasoning, to ensure uniform and defect-free drying in reasonably short periods.

Timber in sections thicker than 10 cm, as used in railway sleepers, beams and rafters in buildings and structural members in bridges, dries very slowly. Therefore, it is uneconomical to kiln-season such material, which must only be air-seasoned.

Planks over 5 cm in thickness and scantlings thicker than 7.5 cm × 10 cm (such as used for door and windows frames) also need slow seasoning to prevent drying defects. To make kiln-seasoning economically feasible for these sections, they should be partially air-seasoned to about 25% moisture content after which seasoning can be completed in a kiln. Kiln-seasoning of such sections, directly from the green stage, can be adopted only if the time factor is important and increased seasoning cost immaterial. For ordinary uses, these sections are also generally air-seasoned. Timber planks 5 cm and below in thickness (such as used for door leaves, furniture, etc.) may be kiln-seasoned directly from the green stage or air-seasoned.

SPECIAL SEASONING METHODS

These processes are sometimes adopted, in preference to normal kiln-seasoning, for reducing drying time or for obtaining improved quality of drying or for both.

High-temperature drying.—This process consists in kiln-drying timber (usually in chambers of metal construction) at temperatures above the boiling point of water, i.e., 100° C, in air-water vapour mixtures. When carried out at these temperatures under total exclusion of air from the kiln, the process is known as superheated steam drying. This process has been used commercially, to some extent, for the quick drying of coniferous woods in Europe and Canada.

Experiments carried out at the Forest Research Institute, Dehra Dun, on a few Indian hardwoods have indicated that 2.5 cm thick planks of certain hardwoods can be seasoned within only ¼th to 1/5th of the time taken under conventional schedules with just a tolerable amount of drying degrade, but in other cases the timber suffers severe collapse and deformation. Trials made with hardwoods in the Western countries also have not been entirely successful. In spite of the significant reduction in drying time, it has not been found possible so far to recommend this process for commercial drying under Indian conditions.

Chemical seasoning.—This consists in the application of a hygroscopic or anti-shrink chemical or both, to green wood prior to air- or kiln-seasoning. Green timber is usually soaked in a water-solution of the chemical for a suitable period depending upon its thickness, so as to diffuse it to a depth of about 1/10th the thickness, after which it is air- or kiln-seasoned in the usual manner. The chemicals maintain the outer zones at higher moisture content during drying than that occurs with untreated wood, or reduce the shrinkage tendency of the outer zones by bulking up the walls of the wood-cells. The tendency of wood to surface-cracking is thereby reduced, and this appears to be the main advantage. Common salt is used in the U.S.A. for reducing surface-cracking during the seasoning of thick timbers, but the surface-absorbed salt sweats in humid weather and corrodes metals. Urea and polyethylene glycol are better in this respect. The latter has been used for chemical seasoning as well as dimensional stabilization on half-wroughts of gun-stocks, wood carvings, and other costly items. Experiments on chemical seasoning of thick and refractory timbers are in progress at the Forest Research Institute, Dehra Dun.

Solvent seasoning.—In this process the timber is stacked vertically in a vapour-tight chamber and a heated water-miscible organic solvent, such as acetone, is circulated over the timber by means of a pump. The solvent extracts the moisture from wood in liquid form, as also extractive such as terpenes, rosin, etc. The extract is distilled to recover the acetone. The solvent absorbed by wood is also recovered by passing hot air over the wood and condensing the vapours of the solvent. The entire process is carried out at atmospheric pressure.

The process is reported to reduce the drying time considerably and to remove pitch and resins, thereby yielding clearer timber. The acetone flows down vertically through sapwood boards, thus bringing the drying medium into intimate contact with all the wood, and not merely the surface as in kiln-drying. It does not pass through heartwood boards in the same manner, as they are comparatively impermeable. The feasibility of this process for quick drying of refractory hardwoods has not so far been tried in India. It has so far been applied to a limited extent to pine (softwood) in the U.S.A., and in this case it is reported to be comparatively more economical than kiln-drying. It needs an elaborate equipment.

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High-frequency drying.—Wood placed in a powerful electric field, oscillating at more than a million cycles per second, is heated quickly throughout to a temperature above the boiling point of water. In permeable woods, drying by this method can be very rapid. The high temperatures, however, weaken the wood and lower its resistance to the pressure under which water is removed from the interior zones in this process. This often causes local explosions or splits in the wood.

This process has been applied to a limited extent in the U.K. for the drying of small-sized timber for brush-backs, broom-handles, etc. It may not be useful for refractory hardwoods. Apart from the very expensive equipment, high-frequency heating is also too expensive to be used for drying wood owing to the high cost of electric power in the developing countries.

Vapour drying.—Wood can be dried by subjecting it to vapours produced by boiling a water-immiscible organic solvent such as xylene. Wood is heated by the hot vapours in a suitable chamber. Atmospheric pressure and a temperature of about 149° C(300°F) are used during the heating. The vapour penetrates the surface zones of wood and condenses, giving off latent heat of condensation. This heats up the water which come off on the application of a vacuum. The mixed vapours of the chemical and water are continuously drawn off from the chamber and condensed, the water is separated off and the chemical recovered. The final vacuum removes most of the absorbed chemical from the wood. By giving a suitable schedule the moisture content can be reduced substantially.

The process has so far been used to a limited extent only for the quick conditioning (partial drying) of railway sleepers and poles for further preservative treatment. It needs elaborate equipment and highly skilled supervision.

Vacuum drying.— In this process green wood is placed in a chamber, in which arrangement for heating the wood either by infra-red radiation or by heating up the gas in the chamber is provided. A vacuum is maintained by continuously removing the vapours from the chamber.

The vacuum materially aids in the removal of free water, particularly from the surface zones of wood for a short period at the start of drying. The removal of free water from the interior zones and, therefore the further rate of drying is, however, still governed by the permeability of wood, as in ordinary kiln-drying. Moreover, very rapid transfer of heat to the wood is called for, if a rapid rate of drying is to be maintained once the surface moisture has been removed. Heat transfer through the rarified atmosphere within the chamber presents a great practical problem.

The only practicable form in which the process has been used is the steaming-cum-vacuum process. It is used for quick conditioning of thick timbers, sleepers and poles preparatory to preservative treatment. No vacuum process has so far come into general use anywhere for the seasoning of timber in the normal sense.

Boiling in oil.—Wood can be rapidly dried by submerging it in hot oil and boiling off the water. Petroleum oil and creosote, which have boiling points considerably above that of water, have been tried. The boiling is very rapid in permeable wood. In refractory wood the process causes too rapid drying of the surface zones resulting in cracking, splitting and severe drying stresses. This process also has been used only for the quick conditioning of thick timber, sleepers, poles, etc., prior to preservative treatment.

Care of Seasoned Timber

It need hardly be emphasized that dried timber should be fully protected from the weather. For instance, any load of kiln-dried timber transported by lorry should be well sheeted down in wet weather.

Ideally, of course, dried timber should be kept in atmospheric conditions corresponding roughly with the moisture content at which the wood is required when manufactured. In a heated store, the equilibrium moisture content can be adjusted to some extent by varying the amount of heating, for this in turn will control the humidity and the efficient operator can, with the aid of hygrometer tables and an equilibrium moisture content chart, obtain approximately the conditions required.

When kiln-dried timber has to be kept for any length of time in an unheated shed or store, it should be kept tightly close piled so that moisture content variation will occur in only the outer boards or planks. Short dimension stock, with a high proportion of end grain exposed, is liable to

pick up moisture rather rapidly, and if piles of such material have to be left for long in the open sheds in winter or rainy months they should, wherever possible, be covered with tarpaulins.

STORAGE OF LOGS

Bulk timber in the form of logs often requires storing pending its conversion. During the period of storage, actual loss of moisture from logs is of little significance. Experiments have shown that even after several years of storage, some species have nearly the same amount of moisture in the centre of the logs as they had when the trees were felled. The outside portion of such logs will probably have dried out to a certain extent. Owing to the tension stresses set up in the outer layers, surface cracks develop. In additions, unless the particular species happens to be fairly immune to insect and fungal attack, some loss from these causes is inevitable.

It is, however, possible to store the logs under conditions which protect them against rapid drying, and also keep them free from attacks of insects and fungi. One of the best and most practical ways to achieve this result is to store them under water (Fig. XIV-13, facing page 214).

During water storage, the logs should be completely submerged under water. If the water is stagnant, as in the case of artificial log ponds, the water should be changed, say once a fortnight to remove the fermenting material. The removal of bark greatly reduces the chances of the logs being attacked by insects. Entire bark should, therefore, be removed before the logs are stored under water.

In case it is not possible to store logs under water, they should be stored on land over raised foundation, preferably under shade with the ends coated with suitable moisture-retardant paint or composition. The bark in this case also should be removed, except for the which species are very prone to surface cracking. Before stacking on ground a prophylactic preservative treatment should be given, particularly in case of species prone to insect and fungus attack.

REFERENCES

Ghosh, D.P. . . .	1962	A note on the economy in construction of single stack and double stack type of kiln chamber; *Indian For. Leafl.* No. 168, Wood Seasoning; Manager of Publications, Delhi.
I.S.I.	1958	Indian standard code of practice for seasoning of timber, IS : 1141-1958; Indian Standards Institution, Delhi.
Kapur, S. N. . . .	1935	Manual of Air-Seasoning of Indian Timbers; Manager of Publications, Delhi.
Mathewson, J. S. . .	1930	The air-seasoning of wood ; *U.S. Deptt. Agric. Tech. Bull.* No. 174; U.S. Govt. Printing Office, Washington.
Rasmussen, E.F. . . .	1961	Dry Kiln Operator's Manual; Agriculture Handbook No. 188; U.S. Govt. Printing Office, Washington.
Rehman, M.A. . . .	1940	Experiments on the air-seasoning of *Pinus longifolia* (chir) sleepers in the East Almora Division, U.P.; *Indian For. Rec.* (N.S.), 2 (5), Utilization Manager of Publications, Delhi.
Rehman, M.A. . . .	1941	Experiments on the air-seasoning and passing of sal sleepers; *Indian For Bull.* (N.S.), No. 97, Utilization ; Manager of Publications, Delhi.
Rehman, M.A. . . .	1941	Stacking timber for air-seasoning; *Indian For. Bull.* (N.S.), No. 95, Utilization ; Manager of Publications, Delhi.
Rehman, M.A. . . .	1941	Note on a hot-air kiln for seasoning half-wroughts of shuttles, bobbins, helves, picker arms, etc.; *Indian For. Leafl.* No. 5, Utilization ; Manager Publications, Delhi.

Rehman, M.A. . . .	1943	Furnace heated veneer drying kiln ; *Indian For. Leafl.* No. 57, Utilization: Manager of Publications, Delhi.
Rehman, M.A. . . .	1944	Conditioning chamber for plywood; *Indian For. Leafl.* No. 65, Utilization; Manager of Publications, Delhi.
Rehman, M.A. . . .	1952 1953 1956	Seasoning behaviour of Indian timbers, Parts I, II & III; *Indian For. Bull* (N.S.), Nos. 154, 170 & 198, Wood Seasoning; Manager of Publications, Delhi.
Rehman M.A., Ghosh, D.P. & Mehra, M.L. . .	1960	Design and operation of an improved type of indirect-heated thermal-circulation furnace kiln ; *Indian For. Bull.* (N.S.), No. 226 Wood Seasoning; Manager of Publications, Delhi.
Rehman, M.A. & Kapur, I.K.	1941	An indirect-heated internal-fan furnace kiln for drying packing-case timbers; *Indian For. Bull.* (N.S.), No. 98, Utilization ; Manager of Publications, Delhi.
Rehman, M.A. & Kukreti, D.P.	1961	Experiments on air-seasoning of B.G. sleepers of chir at Hardwar during Feb-June 1960 ; *Indian For.* 87 (5) Dehra Dun.
Rehman, M.A. & Tewary, D.D.	1962	Types of seasoning-kilns suitable for drying Indian woods ; *Indian For. Leafl.* No. 155 (Revised), Wood Seasoning ; Manager of Publications, Delhi.
Sharma, S.N., Bali, B.I. & Rehman, M.A. . . .	1961 1962	Experiments on the high temperature drying of some Indian timbers, Parts I & II ; *Indian For. Bull.* (N.S.), Nos. 230 & 236, Wood Seasoning ; Manager of Publications, Delhi.
Trotter, H. . . .	1940	Manual of Indian Forest Utilization ; Humphrey Milford, Oxford University Press, London.
Trotter, H. . . .	1944	Common Commercial Timbers of India and their Uses ; Manager of Publications, Delhi.

CHAPTER XV

COMPOSITE WOOD AND IMPROVED WOOD

Introduction

Wood has been a favoured material for different structural and other purposes because of its ease of working, good strength, elastic, thermal, acoustic, electrical and other properties, and ready availability, and because of the varied choice it provides to meet different structural needs requiring different strength moduli and figures of merit. The use of wood has, however, certain disadvantages, viz., (a) natural growth defects, such as knots, spiral grain, etc., (b) hygroscopicity with its attendant defects like 'working' (i.e., alternate swelling and shrinking induced by changes in atomospheric conditions), (c) lack of strength balance due to anisotropy, and (d) lack of strength in compression and shear, non-uniformity, etc. Various processes and methods have been developed, most of them in recent years-to get over or partially remove these defects, and broadly, they consist either in developing large pieces from relatively small pieces or in treating and modifying wood by means of pressure, heat and chemicals. Incidentally these developments also help in utilizing waste wood and wood of inferior species. These aspects are dealt with below under two heads, viz., Composite Wood and Improved Wood.

COMPOSITE WOOD

Definition and scope

Composite wood is a general term for built-up, bonded products, consisting either wholly of natural wood, e.g., plywood or coreboard, or of wood in combination with metals, plastics, etc.

The following forms of composite wood are dealt with here :

(A) Plywood, (B) Laminated wood, (C) Coreboards, (D) Sandwich boards, (E) Fibreboards, and (F) Particle boards.

(A) PLYWOOD

Histrorical development of plywood

Before plywood was thought of, thin sheets of expensive and rare woods had been used as facings on less costly woods, particularly for furniture. This use of veneers is very old and dates back to the Egyption sculptures of about 1500 B.C. Archaeologists have found evidences of it in the tombs of the Pharoahs. How the original veneers were cut has not been discovered, but they were fixed with some kind of animal glue. Then there was a long interval when only solid wood was used. Veneering was revived in the late 17th century in Europe, mainly for ornamental purposes. In the second half of the 19th century, plywood was used for tea-chests in the China tea trade. Commercial production of plywood originated comparatively recently, i.e., in the eighteen-eighties, when the first factories producing plywood were erected in Russia. The industry has since spread to all parts of the world, wherever large timber resources are available and where widespread employment of the material makes local manufacture profitable.

General description of plywood

Plywood is a term applied to glued wood construction built of veneers in such a manner that the grain of each veneer is at right angles to that of the adjacent veneer in the assembly. This method of assembling wood components is referred to as cross-banded construction, which separates plywood from laminated wood where the grains of successive layers are parallel. The most significant advantage, apart from others, is the modification of strength properties to maximum advantage.

The outer plies in plywood panel are called *faces*, or *face* and *back*, and the centre ply or plies, the *core*. The core may consist of veneer timber or various combinations veneer and timber.

The different plies may vary as regards number, thickness and kinds of wood. Plywood may consist of any odd number of plies. The simplest structure is of three plies. In panels having more than three plies the layers between the core and the face or back are called 'cross-bands'.

Advantages of plywood

The cross-banded construction of plywood yields many advantages over the use of solid wood. The most significant advantage is that it possesses dimensional stability, which is lacking in solid wood. Plywood has the strength distributed in both directions. There is little or no tendency to split. As veneers can be cut from big logs at their greatest width, plywood can be made in big sizes. Water-proof plywood, made with special glues, is very resistant to the action of water, even if soaked or exposed for a very long time. Plywood can also be moulded to various shapes, and will retain those shapes more or less indefinitely.

Wood is anisotropic in character, showing different properties in each grain direction. For example, the shrinkage and swelling with changes in moisture content is much less in the longitudinal direction than in the radial and tangential directions. In plywood construction, the shrinkage and swelling are approximately equal and substantially less than the radial or tangential changes in solid wood.

Balanced construction

The tendency of plywood to warp as a result of stresses caused by dimensional changes is eliminated by balanced construction. This construction consists in arranging the plies about the core, in such a manner that for each ply there is an opposite, similar and parallel ply, The plies are usually matched with respect to species, thickness, original moisture content and type of veneer. It is for this reason that flat plywood panels are invariably constructed with an odd number of plies. If only two plies are glued together with the grains at right angles, each ply tends to distort the other with changes in moisture content, and cupping usually occurs. Similar results are produced when an even number of plies are used. This balanced construction is more important in thin panels than in thick panels where some departure may be permitted, especially in the case of the outer plies where considerations of grade and appearance dictate the type of veneer to be used.

Manufacture of plywood

1. *Location of plywood mills.*—On an average, the volume of round wood required is about 2 to 2½ times the volume of the product in plywood; up to 60 per cent of each log may be wasted. To avoid handling costs and transport on so much material that constitutes a waste, it is usual to have plywood mills as near to sources of supply of logs as possible.

2. *Manufacturing processes.*—The essential processes in plywood manufacture consist of :

(i) Preparing the veneers, namely, faces, cross-bands and cores, for gluing ;

(ii) Drying of veneers;

(iii) Mixing and spreading the glue or adhesive ;

(iv) Pressing the glued lay-up into a panel;

(v) Conditioning of the panels; and

(vi) Trimming, sanding and storage.

These processes are briefly described below :

(i) *Preparation of veneers*

This is done in the following stages : (a) softening the logs, (b) cutting, and (c) jointing and splicing.

(a) *Softening the logs.*—The logs are first suitably softened by boiling or steaming. Both processes are equally efficient, but steaming is more popular as it is easier to control. During the process the wood becomes pliable and the moisture content becomes equalized throughout the log. The period of steaming or boiling will vary with species, log sizes, etc.

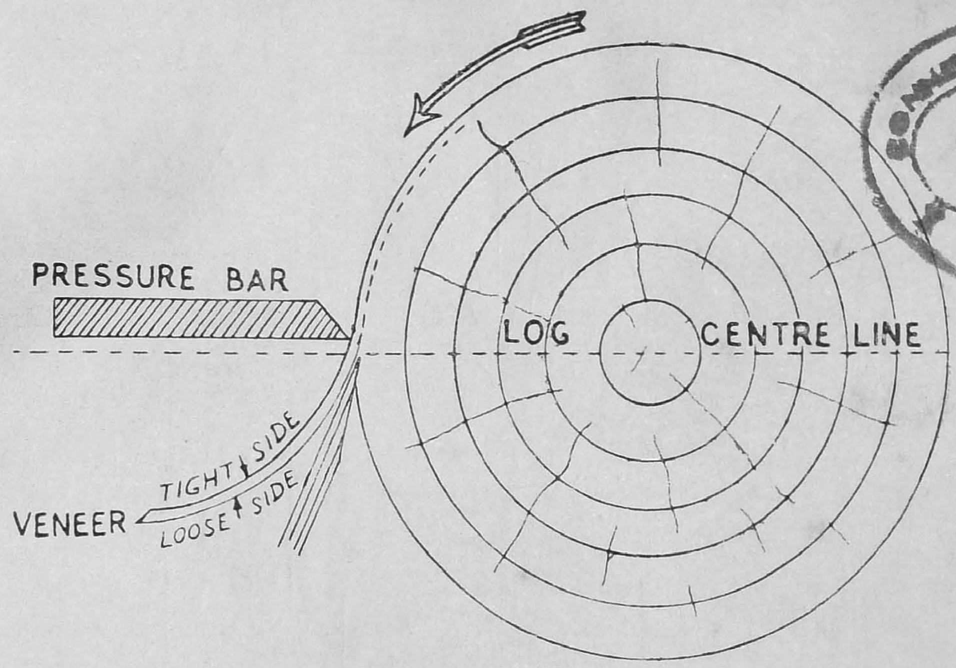

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Fig. XV—1. Log-peeling, rotary cutting on a veneer lathe.

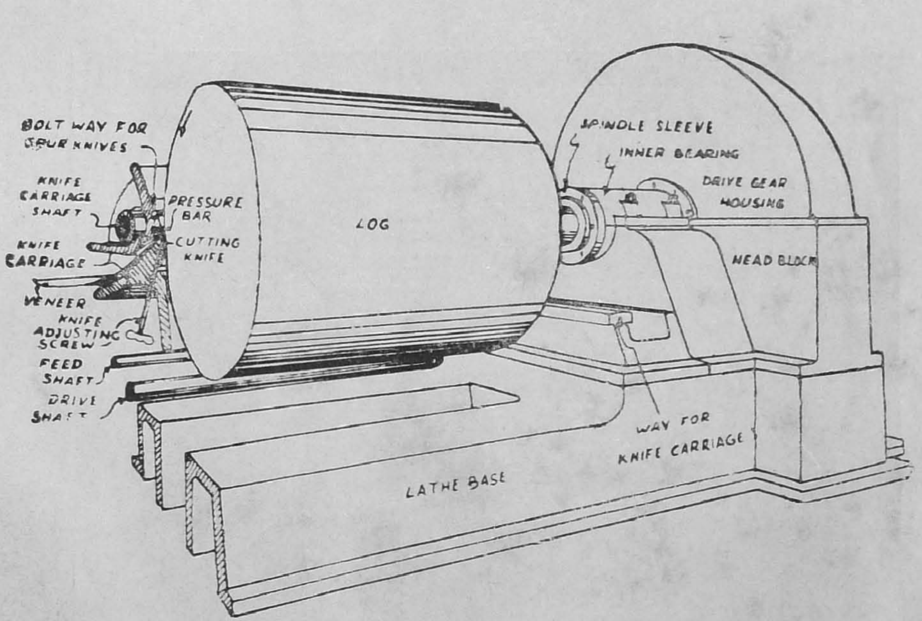

Fig. XV—2. Perspective view of standard lathe with left end removed to show cutting mechanism.

(Adapted from 'Modern Plywood' by T. D. Perry).

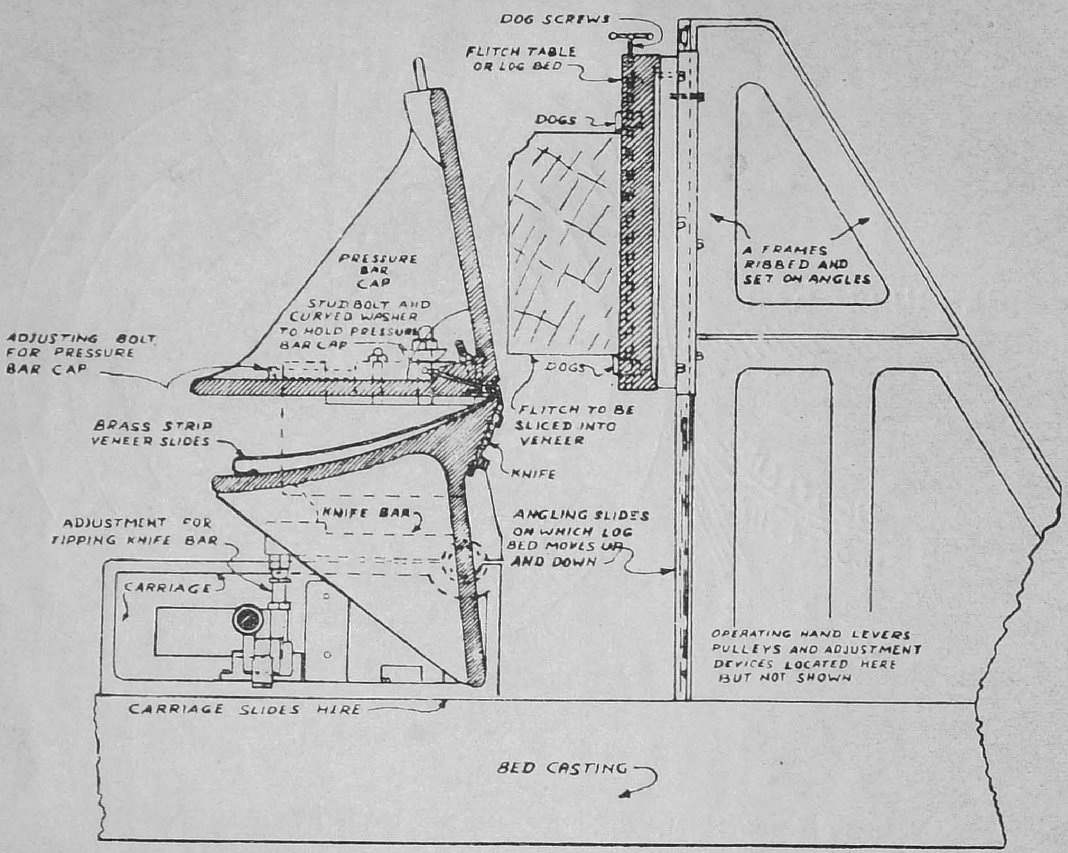

Fig. XV—3. Cross-section diagram of a standard veneer slicer. (Adapted from "Modern Plywood" by T. D. Perry).

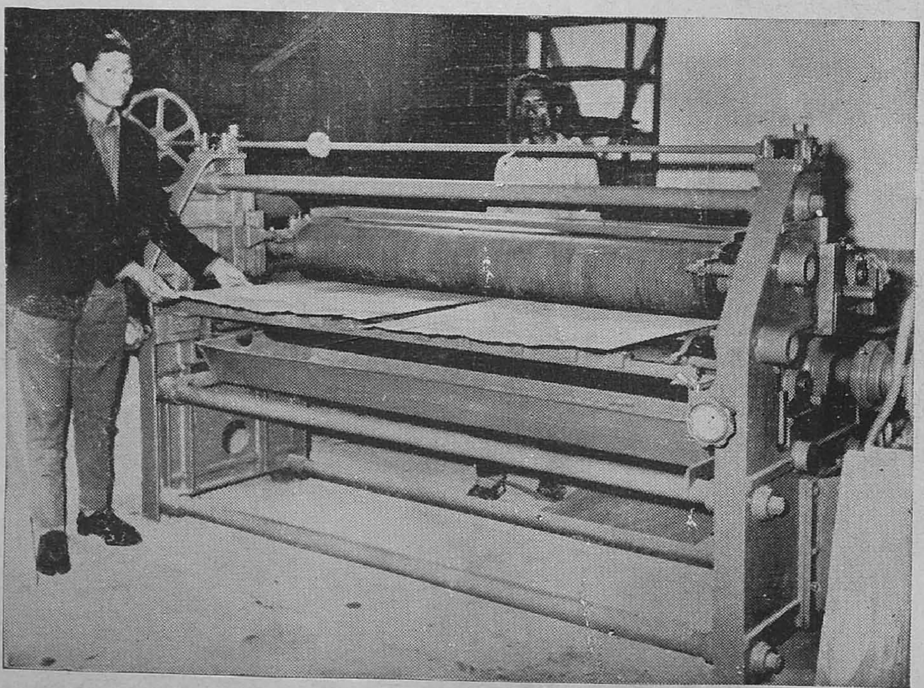

Fig. XV—4. Glue spreadeı

(b) *Cutting.*—After softening, the logs are cut into veneers by methods which are described under "Veneers for Plywoods and Laminated Structures" in Chapter XXIV ("Specialized Uses of Wood") Veneers are usually produced by two methods, viz., (1) rotary peeling, and (2) slicing.

In the process of peeling, the veneers come out as if a roll of paper is being unrolled (Fig. XV—1 & 2). The maximum length of logs used for peeling is about 255-280 cm. The minimum thickness which can be peeled may be as low as 0.05 mm (1/500 in.). The common thicknesses of rotary-cut veneers are 1.25 mm, 1.5 mm and 2.5 mm.

In slicing, the veneers are prepared in the same way as bread is sliced (Fig. XV—3). Sliced veneers usually range from 0.6 mm to 1.25 mm, but the bulk of face veneers are cut 0.8 mm, 1.0 mm, or 1.25 mm in thickness. Slicing is generally done for getting ornamental veneers for decorative plywood.

(c) *Jointing and splicing.*—The defects in the veneers obtained are cut out. In this process, a number of veneers may be produced which are too narrow to cover the desired width of the plywood sheets. These need not be wasted; they can be accurately trimmed on a jointer and joined perfectly together by gluing on a splicer.

(ii) *Drying of veneers*

Freshly-cut veneers are usually very wet and are unfit for gluing in that condition. Also they are liable to the attack of moulds, blue stain and other wood-destroying fungi. Hence it is necessary to dry the veneers as quickly as possible. Formerly, plywood factories used to dry the veneers in the sun or in kilns. Now-a-days steam-heated mechanical dryers are used for the most part. These mechanical dryers are mainly of three types viz., (1) Roller type, (2) Platen type, and (3) Band type. These modern dryers ensure rapid drying and high output of veneers.

(iii) *Mixing and spreading the glue*

Adhesives used in the composite wood industry are discussed in a separate section below. But for the development of modern synthetic resin adhesives the present progress in the industry would not have been possible, and would might have become a back number as it would not have been able to compete with alloys and plastics. To began with, for the most part animal glue, starch glue, etc., were used in plywood manufacture. Later, they were replaced by blood albumin and protein glues like casein, etc., because these were water-resistant. For about a decade now, the field has been taken up mainly by synthetic glues like urea-formaldehyde (U.F.), phenol-formaldehyde (P.F.), etc. Glues can be classified in a number of ways, according to their durability, usage, properties, etc. Thus there are thermosetting and thermoplastic glues, weather-proof and weather-resistant glues, gap-filling and contact glues, etc. Synthetic glues are more resistant to water and organisms causing decay, and are therefore preferred.

Adhesives used for plywood manufacture are carefully mixed with the correct proportions of the ingredients by weight or, where liquid ingredients are used, by volume. Glues with short working life are prepared in small batches. Even where a glue remains stable for long periods it is desirable to prepare small batches and to mix frequently.

The veneers are coated with the prepared adhesive by means of a spreader (Fig. XV—4) or otherwise. The amount of glue spread is usually described in terms of quantity of glue in kilograms per 1000 sq m of glue-line. The time interval between the spreading operation and the application of full pressure upon the plywood panel is known as the *assembly time*. If there is appreciable hardening of the glue on the surfaces of the wood before full pressure is applied, the strength of adhesion is considerably reduced. In some cases there is a minimum assembly time as well as a maximum one.

When glue is coated in a liquid form, the core or cross-bands of the panels are usually coated on both faces with glue by means of a mechanical roller spreader. Scrapers or other devices regulate the thickness of the glue layer according to the character of the spreader being used.

One type of phenolic resin glue is available in the form of a thin film. The film is cut to the required size and inserted between sheets of the veneer. It finds special application in the case of very thin veneers which cannot conveniently be handled by a glue spreader.

(iv) *Pressing*

The glue-coated veneers are assembled in proper order and subjected to pressure to ensure proper alignment of components and intimate contact between the wood and the glue. While under pressure, the assembly is allowed to cure at least partially. Depending on the type of glue, the pressing is done either at room temperature (*cold-pressing*) or at high temperatures (*hot-pressing*). Virtually all pressing is done in hydraulic presses, using pressures of 7 to 18 kg per sq cm. The higher pressures (14 to 18 kg per sq cm) are used with very dense woods, moderate pressures (10 to 14 kg per sq cm) for woods of medium density, and lower pressures (7 to 10 kg per sq cm) with low-density woods. The time of pressing and the temperature to be used will depend on the type of glue, thickness of the pack, etc.

Generally, hot-pressing is adopted as it gives faster output and better product. Where hot presses are not available, recourse is taken to cold-pressing, using rataining clamps to increase the output.

The two types of pressing are briefly described below ;

(a) *Hot-pressing.*—In hot-pressing, several panels may be placed together between the heated plates. With thick panels only one panel is pressed in each opening. Hot presses usually have many plates, so that a number of panels can be glued in one pressing operation. The time required in the hot press depends on the thickness of the material being glued and on the character of the glue being used. The glues can be cured at various temperatures from 100°C to150°C. Since the innermost glue-line must be treated to the required temperature, the pressing time depends on the distance the heat must travel from the plates to reach this glue-line. The time may vary from a few minutes for thin panels to an hour or more for panels 5 cm to 7.5 cm thick. The amount of pressure required in the hot press varies, as already mentioned, with the kind of wood being used. In any case, while the pressures should not be so great as to crush the wood under the conditions of heat and moisture obtaining in the panel, they should not be so low that the glue will not be pressed out into a thin continuous film in complete contact with the two surfaces to be joined.

(b) *Cold-pressing.*—For cold-pressing, the panels are stacked and placed in the press as soon as possible after the application of the glue. The permissible interval between the application of the glue to the first veneer and the application of pressure to the stack of panels various with different glues, up to thirty minutes or longer, and this should be strictly observed. The panels are stacked to a height of 75 cm or more, with flat caul boards separating the pile into groups of two to seven or more panels. Rigid, smooth press-boards are placed at the top and bottom of the stack. The assembly is then placed under pressure. Two methods are in vogue for applying the pressure and for maintaining it on the panels. The one in common use consists in applying the pressure by means of an hydraulic press and keeping the panels under pressure by means of retaining clamps; the panels are left in the press long enough to apply the required load and to fix the retaining clamps in place. The bundles of panels along with the clamps are then removed and left until the next day for the glue to set completely. In the other method, the panels are placed in presses and left for a few minutes until the glue takes an initial set; the panels are then removed from the press and the complete curing of the glue is allowed to take place under little or no pressure. Control of pressure is important in cold-pressing in the same way as in hot-pressing operations. Usually the pressures applicable for the latter are suitable for the former also.

(v) *Conditioning of plywood panels*

After the plywood is pressed, either hot or cold, it is necessary to condition it in a conditioning chamber, in order to bring the moisture content of the plywood to about 12%. In hot-pressed plywood, the veneer is likely to lose considerable quantities of moisture during and immediately after pressing. It is customary to add moisture after pressing at high temperatures, by sponging them with water or exposing them to controlled humidities. On the other hand, panels glued with common aqueous glues take up a good deal of moisture in gluing; they are often placed on stickers and run into a drying kiln at controlled temperature and relative humidity. The drying is sometimes allowed to take place at room conditions but this is slow and, therefore, uneconomical.

(vi) *Trimming, sanding and storage*

After conditioning, the panels are trimmed to the exact dimensions required and sanded if necessary. The finished panels are then packed for despatch or storage. They must be stored under conditions that will not appreciably change their moisture content; the store-room should be well ventilated and care taken that wood borers do not find their way to the stock. Stacking in solid piles, with the panels lying one over the other and with a cover over the top of each pile to protect against changes of moisture content, is usually satisfactory.

Moulding of plywood.—Plywood lends itself well to being moulded into various shapes, and the moulding of plywood is one of the important advances made in the industry. The simplest way to bend it is to press it while the glue is still wet, against a solid block shaped to the desired curve, and to keep it pressed there unit the glue has set. The mould has to have two parts, the male and the female. This was the earliest method used, and is still used for simple bends, but it will not work when bends in more than one direction are required in the same sheet of plywood. For this kind of moulding a new technique called *rubber bag* method or *bag moulding* has been evolved; this requires only the male part of the mould. A mould in the desired shape is made from wood or other materials and the freshly-glued plywood is placed upon it. The whole is covered with a sheet of rubber or plastic. The sheet is clamped to a table, and a vacuum is applied so that the rubber sheet takes the form of the mould; the glue-coated veneers get pressed between the mould and the rubber sheet. By a special arrangement the pack is heated from the bottom and the top, and this enables the glue to set. The moulded plywood can be taken out after 10 to 15 minutes. The production is fairly quick. Sewing-machine covers, chair seats, trays, etc., can be produced by this process.

Uses of plywood

Plywood is used for interior walls and partitions in shops, offices and factories, and sometimes even for exterior walls, floors, doors, kitchen cabinets and fitments, and as shuttering for construction of concrete walls. It is much used in the construction of railway carriages and for certain aircraft parts. It is widely used for sports goods—e.g., table-tennis bats, laminated skis—as also for making trunks and other baggage. Manufacturers of radio, wireless and television sets make use of it for the cabinets. In India, slightly more than half the total production of plywood goes into tea-chests for export of tea.

Plywood for special purposes

Most of the plywood produced in India conforms, in general, to the standards established by the Indian Standards Institution. Some plywood, however, is produced to meet specific demands, or to conform to specifications that are drawn up to secure a product suitable for special purposes.

A considerable quantity of plywood is produced with overlays of paper or fabric impregnated with synthetic resins. Frequently an overlay is applied to one face to provide a desired decorative effect combined with good wearing characteristics. This product is widely used for counter and table-tops. If a decorative type of overlay is applied on one face, a plain overlay is usually applied on the back to reduce the tendency to warp that would otherwise result.

Specifications and standards

The quality of plywood and of the veneer from which it is made are covered by Indian Standards Specifications. These cover chiefly the technical provisions relating to the manufacture, inspection and supply of the products; they also cover such matters as dimensions, tolerances, finish, moisture content, inspection, tests, standard plywood sizes, etc.

Plywood industry in India

Though comparatively new, the plywood industry has made rapid progress because of the ready market for commercial and tea-chest plywood. By 1961-62 there were in India 71 factories on the approved list of plywood manufacturers with a total installed capacity of 13.04 million sq.m. Apart from this, there where about 48 small-size factories (unapproved) with a rated capacity of 836,000 sq.m.

Plywood production and trade

Plywood production in India.—The annual production of plywood between 1951 and 1964 was as follows :

TABLE XV-1

Production of plywood in India

(In thousand square metres)

Years	Tea-chests	Commercial	Total
1951	5,634	948	6,582
1955	8,466	1,802	10,268
1960	9,123	6,027	15,150
1961	9,076	6,303	15,379
1962	9,790	7,450	17,240
1963	9,924	9,648	19,572
1964	8,988	10,788	19,776

Note.—The data for 1962, 1963 and 1964 are based on the production from 71 organised units, and excludes the production of 48 small-sized units.

Plywood imports and exports.– India is self-sufficient in respect of plywood production. Exports and imports are small. During the year ended March, 1963, these were as below :

TABLE XV-2

Plywood : Indian Imports and Exports

Category	Imports		Exports	
	Quantity kg	Value Rs.	Quantity kg.	Value Rs.
Veneer sheets	16,560	171,181	215,384	245,730
Plywood including wood faced with veneers	44,340	204,134	241,388	440,030
Total	60,900	375,315	456,772	685,760

International production of plywood.—The world production of plywood reached 16.5 million cu m in 1961. North America is the largest producing region, accounting for 9.7 million cu m or 59 per cent of world production. The five leading producer countries are U.S.A. (8.6 million cu m), Japan (1.5 million cu m), the U.S.S.R. (1.46 million cu m), Canada (1.1 million cu m) and West Germany (0.63 million cu m). These together produced 80 per cent of the world output. The Indian production of about 20 million sq m, equivalent to 100,000 cu m (at 200 sq m=1 cu m) represents only a small fraction of the world output.

(B) LAMINATED WOOD

Laminated wood (Syn. *laminate*) may be defined as a built-up product made of wood layers (called *laminae*), all laid with their grain parallel, and glued or otherwise fastened together. The laminae may

vary as to species, number, size, shape and thickness. Glued laminated wood construction, or the structural material resulting from glued lamination, is called *glulam.*

Manufacture

The process is briefly as follows :

The laminae, which may be thin veneers or boards depending on the purpose for which the lamination is done and the size of the laminated member, are first seasoned in kilns. They are then cut to uniform width and length. If laminae of uniform width are not available, the full width is obtained by edge-gluing strips or boards. Laminae that are short of length are end-joined and glued to the required length. In order to develop joints of maximum strength, the wood surfaces to be glued are cleanly machined so as to fit accurately. The laminae are then arranged in the proper order and fed into a glue-spreader which spreads the glue properly. The glued laminae are then placed on a jig or form for assembling to the required shape, and pressure applied by means of clamps fitted at regular intervals. The pressure of the clamps is distributed uniformly through cauls of wood or metal placed on both faces of the assembled pack.

The purpose of gluing jigs and forms is to permit the assembling of the laminae after glue has been applied to them, and then to draw them to the shape desired in the final product and hold them in that shape under gluing pressure until the glue is set and cured. For gluing straight members, the jig or form generally consists of a flat bed on which the laminae, coated with glue, are laid consecutively. Suitable caul boards are placed on top and bottom of the assembly to assist in distributing the gluing pressure. Curved assemblies are made on jigs of appropriate design. The cured assembly of curved laminated members essentially retains the curved shape. In general, a curved laminated member is less likely to develop spring-back on release from jig or form when made of many thin laminae than when made, for the same depth, of a few thick laminae.

The amount of pressure required to produce a good joint varies within a wide range. The minimum pressure permissible is one that will ensure close contact of the wood surfaces, and hold such contacts until the glue has set. Species of high crushing strength require and withstand higher gluing pressures than woods of lower strengths. With dense woods, satisfactory results may be obtained with pressures ranging from 10.5 to 17.6 kg per sq cm. The corresponding range for soft-wood is from 7 to 14 kg per sq cm.

It has been found that gluing gives better strength than other conventional modes of fastening developing 100 per cent of the strength of the clear, straight-grain lumber against about 85 per cent recorded for other types of fastenings.

If laminated wood is to be used under conditions that raise its moisture content to more than 20%, either the heartwood of durable species should be used or the wood should be treated with preservatives and only highly moisture-resistant glues should be used.

Advantages and limitations of laminated wood construction

Advantages.—The following are among the advantages of using laminated wood :

(1) Glued from dry laminae, the laminated wood remains relatively constant in dimensions under normally dry-use conditions. Hence the development of splits, checks, and loosened fastenings and connections is greatly reduced. In the interest of successful gluing, only dry laminae are ordinarily used.

(2) Laminated structural members can be produced in a thoroughly dry condition in a relatively short time, whereas solid timbers require weeks or months of seasoning, depending on size.

(3) Lamination permits more complete utilization of available supplies, because larger members than are usually available can be built up of short-length and narrow lumber : narrow lumber is edge-glued to increase width and short lengths end-jointed to increase length.

(4) Laminated wood can be produced in special shapes, such as curved arches, curved boat framing, etc., to provide generally improved strength.

(5) In curved form and other special shapes, laminated members permit a more versatile and effective application of wood to architectural design in building construction.

(6) Mixed grades and species can be used in the same structural member. High-strength lumber, as determined by species, density and grade, can be used in the portions that require special strength and appearance, and weaker and less costly lumber in low-stressess portions. Similar selective placement of the laminae to disperse knots and other characteristics is also possible.

Of the above factors, the most important are those relating to size and shape, particularly shape. Arches, which are efficient structural forms, can be made relatively easily by bending thin boards to the necessary curvature and gluing them together. Large solid timbers cannot be bent to such curvatures, and when segmental timbers are bolted or otherwise fastened together, the resulting member does not have the strength and efficiency of a curved laminate.

Limitations.—The main disadvantage of glued laminated timber is its relatively high cost, and so its use in constructions for which natural timber is satisfactory is precluded. A further limitation is the difficulty of transport, by ordinary conveyances, of large sizes of laminated wood for any considerable distance. This is particularly so with arch sections which may not pass through tunnels or bridges having limited clearances.

Uses of laminated wood

Parallel-grain or laminated construction has long been used in the Western countries for furniture parts, for cores of veneered panels, and for sports goods. The first use of glued laminated structural members began as early as 1907 in Europe. Since then laminated wood has experienced a steady increase in general use both in Europe and in America. The most extensive application of glued laminated construction has been in Europe, especially Switzerland and Scandinavian countries, where it finds use in the building of aeroplane hangars, auditoriums, exhibition, halls engine houses, garages, churches, greenhouses, gymnasiums, planetoriums, theatres, warehouses, etc. Laminated wood is also suitable for diving boards, wood rolls, pickers-sticks, flooring, boat and ship timbers, aircraft parts, etc.

Experiments have been carried out at the Forest Research Institute, Dehra Dun, on laminated wood with both thick and thin laminations. Laminated skis, snow shoes, tennis racquets, etc., have been produced. Laminated made at the Institute and subjected to weathering in the open, have been found in a satisfactory condition at the end of 10 years. Laminated curved members of 1·3-2·5 cm lamination have been produced in a small way. Aircraft propellers and test fans are usually made of mahogany. Years ago, aircraft propellers made of padauk (*Pterocarpus dalbergioides*) were found to do very well. During last the World War, several propellers and test fans were made of laminated wood from aini (*Artocarpus hirsuta*), chickrassy (*Chukrasia tabularis*), champ (*Michelia cahamvaca*) and bonsum (*Phoebe goalparensis*) with good results. Such propellers can also be used in windmills, stirrers, etc.

The commercial use of laminated wood in India is largely confined to sports goods, particularly tennis and badminton racquets. In view of its acknowledged advantages, it is bound to play an important role as a structural material before long.

Wood-metal laminates

Laminates made of wood and thin metal offer many possibilities. They have the advantage, over ordinary laminated wood, of high cleavage strength and freedom from splitting.

The difficulty in gluing wood and metal has been got over by adhesives like Redux—usually a combination of thermosetting and thermoplastic glues. It is claimed that aircraft wings and fuselage panels bonded with Redux develop shear stresses 25 per cent higher than those with riveted or spot-welded joints. The process is also cheaper than riveting or welding.

The best in wood and metal can be brought out by laminating the two. Furniture has been made from veneered aluminium panels. "Vendura" is a similar product, and is said to have the following advantages : (1) it is resistant to chemical attack; (2) it is resistant to heat, and burns with difficulty; (3) it combines the appearance of wood with the strength of metal; (4) it is more resistant than timber to attack by termite and other insects; and (5) it offers new designs impracticable with wood.

Wood-metal laminates can be used with advantage in gears, bearings, etc., as the metal can conduct away the heat without heating the wood.

(C) Coreboards

Definition and kinds

A coreboard is a composite board built up of a core composed of strips of wood of various dimensions glued together between veneers. It is also written as 'coreboard'.

The following are the main types of coreboards:

Battenboard.—A coreboard having a core made up of strips of wood, each not more than 7.5 cm wide, laid separately or glued or otherwise jointed together to form a slab, which is in turn glued between two or more outer veneers with the direction of the grain of the core strips running at right-angles to that of the adjacent veneers.

Blockboard.—A coreboard having a core made up of strips of wood, each not more than 2.5 cm wide, laid separately or glued or otherwise joined together to form a slab, which is in turn glued between two or more outer veneers with the direction of the grain of the core strips running at right-angles to that of the adjacent veneers.

Laminboard.—A coreboard having a core made up of strips of wood, each not more than 7 mm thick, glued together face to face to form a slab, which is in turn glued between two or more outer veneers with the direction of the grain of the core strips running at right-angles to that of the adjacent veneers. It is also called *laminwood*, but this term is deprecated.

Coreboard constructions aims at lightness of weight and economy in the use of wood, consistent with strength for the purposes in view. It also helps in the utilization of sawmill waste. Recently, coreboards with fibreboard, chipboard or hollow materials as cores have been used in increasing measure. The hollow coreboards with stave grids of veneers or fibreboards, with corrugated or honeycomb arrangement, permit a raw material saving of up to 60 per cent as against solid boards, and are about half as heavy as solid boards. On account of their low weight, better stability and good acoustic and heat insulation properties, such hollow boards are today used chiefly for doors and partitions. Coreboards are today also covered with outer layers of fibreboards, synthetic resin films, metal sheets, etc.

Coreboards are being increasingly used in India, and are manufactured in the form of blockboards, laminboards, flush doors, etc., in a number of plywood factories.

(D) Sandwich Boards

Defination and salient features

Sandwich board is a general term for built-up boards having a core of light material faced on both sides with a relatively thin layer of material having high strength properties.

Sandwich constructions are composites of different materials bonded together into a unit, to achieve a combination of desireable properties which are not attainable with the constituents themselves individually. The two thin facings, also called *skins*, are usually of a strong, dense material, since they are the principal load-carrying members of the sandwich construction. The core of weaker, lightweight material separates and stabilizes the thin facings and carries shearing loads. The entire assembly provides, relatively to its weight, a structural element of high strength and stiffness. The construction is also economical, since the relatively expensive facing material is used only in small quantities and the core materials are in expensive. The materials are positioned in such a way that each is used to its best advantage.

Specific non-structural advantages can be incorporated in a sandwich construction by proper selection of facing and core materials. For a wall-or roof-panel, and impermeable facing can be employed to serve as a moisture-barrier; for a floor panel, an abrasion-resistant facing can be used on the top; and for decorative effects on walls, doors, tables, etc., suitable plywood or plastic facings can be used. Core materials can be chosen to provide for thermal insulation, fire resistance, and also for decay resistance.

Materials used

One of the advantages of sandwich construction is the great latitude it provides in the choice of facings and the fact that, because of the nearly continuous support by the core, the facings can be of thin sheets. The characteristics of the facings determine the stiffness, stability and, to a large extent, strength of the sandwich. The facing materials used include plywood, single veneers or plywood overlaid with a resintreated paper, hardboard, asbestos board, metals such as aluminium, enamelled steel, stainless steel or magnesium steel, wall board, fibre-reinforced plastics or laminates, etc.

For the core many lightweight materials, such as balsa wood (*Ochroma pvramidale*), rubber of plastic foams, and formed sheets of cloth, metal or paper, have been used. The use of paper treated with synthetic resin appears to be promising from the point of view of economy, availability and other advantages of mass production. Flat sheets of dense paper foremd in various ways to make up a much larger volume of low-density, honeycomb-like material may constitute the paper core. For panels likely to be subjected to damp or wet conditions, the paper core has to be treated with resin, which may be up to 15 per cent in quantity, in order to produce the best results. A core material, called *celluboard* or *stringer board*, was developed in the United Kingdom during the war from plywood and strips of spruce, balsa or plywood. A stringer board of bamboo, which can be produced in one operation, has been developed at the Forest Research Institute, Dehra Dun.

Structural properties

The structural properties of sandwich boards will depend on the properties of the facings and cores, and the ratio of the core thickness to thickness of the facings. With increasing thickness of the facings the panel gets stronger and stiffer but heavier.

With the lighweight cores ordinarily used, it is possible to secure sufficient rigidity for a 1.8—m unsupported span on an aircraft floor.

Uses

Sandwich construction finds application in aircraft components, motor torpedo boats, table-tops, flush doors, refrigerators, knock-down containers, landing mats, etc. With increasing data on the design and serviseability, and increasing costs of and shortages in normal constructional materials, sandwich construction may find many other uses that cannot be foreseen at present.

(E) FIBREBOARDS

Definition and kinds

A fibreboard (also written 'fibre board') is a sheet of material made from fibres of wood or other ligno-cellulosic materials. The wood or other vegetable material is first defibrated or pulped, and the fibres are then interfelted into a mat and consolidated by pressure, heat, etc. Bonding agents and supplementary materials may be added at the felting stage to improve certain properties like mechanical properties, resistance to moisture, etc. Such boards are often designated according to the purposes to which they are put, e.g., *Building board Insulating* (or *Insulation*) *board, Wallboard*. Fibreboards are also used as core material in coreboards and sandwich boards.

Fibreboards are manufactured in densities ranging from 32 to 1,440 kg per cu m. The lower density boards are used primarily as insulation, and the higher density boards as structural materials or wearing surfaces. The boards are classified on the basis of density. The *British Commonwealth Forest Terminology* distinguishes three types, viz., *hardboard* (density not less than 481 kg per cu m), *wallboard* (density between 400 and 481 kg per cu m, also applicable to a particle board of this density), and *softboard* (density less than 400 kg per cu m). In India, fibreboards are classified as *insulation board* (density 445 kg per cu m), *wallboard* (density 481 kg per cu m), *medium hardboard* (density 481 to 890 kg per cu m), *standard hardboard* (density more than 890 kg per cu m), and *super hardboard* (or tempered hardboard),

Hardboards are generally classified with reference to the method of manufacture, the density and other relative mechanical and physical properties, into the following types:

(1) *Semi-hardboard.*—A homogeneous fibreboard having a density exceeding 480 kg per cu m but not exceeding 800 kg per cu m.

(2) *Hardboard.*—A homogeneous fibreboard of density more than 800 kg per cu m but not more than 1,200 kg per cu m.

(3) *Super hardboard.*—A hardboard which has been further treated in the course of manufacture to increase its strength and water-resistant capacity; it has a density exceeding 1,200 kg per cu m but not exceeding 1,450 kg per cu m.

Manufacture

Fibreboards are made from agricultural or forest waste materials, e.g., jute sticks, mustard stalks, tapioca stem, areca-nut husk, coconut husk, bagasse, reeds, lops and tops in forest fellings off-cuts and rejections in wood conversion, waste veneers, etc. Several standard processes are in vogue for making fibreboards— Masonite, Asplund, Bauer, etc. The manufacture is for the most part and adaptation of the paper-making process: the raw material is defibrated and reduced to a pulp and then felted into a mat from a water slurry on the screen of a paper machine; the wet mat is then compressed and dried into a compact sheet under controlled conditions of temperature and pressure. In a modification of the conventional wet-felting process, known as the semi-dry process the fibres are carried in an air-suspension, instead of a water-suspension, and air-felted into a mat; the mat is then compressed in a multiplaten press to produce the board. In the wet processes lignin is partially hydrolysed and serves as a natural binding agent. With moisture content, temperature and pressure properly controlled, a natural ligneous bond may be produced in the dry processes also; in some dry process boards however, small quantities of synthetic resin adhesives are added to serve as a binder. Varying conditions of pressure time and temperature are employed to make different kinds of fibreboards. Synthetic resins, like phenol-formaldehyde, are sometimes added to the pulp in order to improve the strength and water-resistant properties of the board. Wood preservatives can also be introduced into the boards so as to increase their durability.

Production in India

The fibreboard industry is well developed in Western countries, but was started only recently in India. Against a fibreboard consumption of 19 kg per capita in Sweden, the Indian consumption is only 0.03 kg per capita. There are only three plants at present in India, viz., Anil Hardboards, Bombay, Western India Plywood, Baliapatam (Kerala), and Assam Hardboard, Gauhati (Assam). Their total capacity is 36,750 tonnes per annum. The annual consumption of fibreboards in India is expected to reach 1,50,000 tonnes by 1975—10 per cent as softboards and the balance as hardboards.

The Forest Research Institute, Dehra Dun, has experimented on a large number of woods, barks, etc., for the production of fibreboards, e.g., areca-nut husk, tapioca stem, bark of *Araucaria* spp. sal (*Shorea robusta*) and kanju (*Holopteea integrifolia*), wood of blue pine (*Pinus wallichiana*), haldu (*Adina cordifolia*), toon (*Cedrela toona*), white cedar (*Dysoxylum malabaricum*), mullilam (*Fagara budrunga*), etc.

Uses

Fibreboards are manufactured primarily for use as panels, insulation and cover materials in buildings and for components of cabinets cupboards and other constructions requiring flat sheets of moderate strength.

(F) Particle Boards

Definition and types

A particle board is a board (or sheet) constituted from fragments of wood and/or other ligno-cellulosic materials (chips, shavings, flakes, splinters, sawdust, etc.), bonded with organic binders with the help of one or more agents like heat, pressure, humidity, catalyst, etc. Such boards are often designated according to the purposes to which they are put, e.g., *Building board, Insulating board, Wall-board.* Particle boards are also used as core material in coreboards and sandwich boards.

The difference between fireboards and particle boards is that in the former the basic particles is essentially pulp made up of individual fibres or small clumps of fibres, while in the latter the basic material consists of larger units in the form of chips, flakes, splinters, etc., that exhibit many of the characteristics of the original wood. Due to this fact, fibreboards depend for their cohesiveness upon the mechanical felting of the fibres, brought about by the formation of a natural ligneous bond on the application of heat and pressure and augmented, sometimes, by the addition of a synthetic resin adhesive. Particle boards, on the other hand, depend almost entirely on the adhesive additive for their cohesiveness. Particle boards vary much more in appearance and properties than do fibreboards.

Common types of particle boards are the following :

Chipboard.—A particle board made from chips. It is made in varying thicknesses and may be surfaced with paper, veneers, plastic materials, etc. Syn. *Binder board.*

Flake board.—A particle board in which the wood is largely in the form of flakes, giving the surface a characteristic appearance.

Shaving board.—A particle board in which wood shavings are the chief constituent.

Depending on their density, particle boards have been classified as follows :

(i) Low density boards—specific gravity 0.2—0.4.

(ii) Medium density boards—specific gravity 0.4—0.8.

(iii) High density boards—specific gravity 0.8—1.2.

Manufacture

Particles of waste wood, in the form of flakes, shavings, splinters, etc., or chips and particles obtained by converting the raw material in a chipper, are usually screened to get particles of more or less uniform size. The oversized particles are reprocessed and used. Very fine particles demand a large quantity of adhesives and are, therefore, not used. The screened particles that are to go into the boards are then run through a drier to drive off any excess moisture. The dried particles are then mixed thoroughly in mechanical mixers with a resin adhesive, other additives such as wax or preservatives being also sometimes incorporated into the mix. The mix is then formed into particle boards, either by flat-pressing in a hot press at a suitable temperature and pressure or by continuous extrusion through two rigidly mounted heated platens. In both the processes, the thickness of the board is controlled by regulating the spacing between the platens. Consolidation to the desired density is attained by controlling the pressure, heat and quantity of the mix.

Particle boards vary more than fibreboards in their properties, the important determinant factors being : (1) type and size of particle, (2) type of manufacture (extruded or flat process), (3) kind and amount of resin, (4) distribution and orientation of particles, (5) density, and (6) the quality of manufacture.

Production in India

The manufacture of particle boards originated in Germany soon after World War II to make up for the acute shortage of building materials. These boards are now being made in all advanced countries.

In India, there are now (1967) six units in production with a total installed capacity of 24,000 tonnes per year. A few more are to commence production soon. Nineteen more units have been licensed.

The Forest Research Institute, Dehra Dun, has carried out extensive experiments on the production of particle boards from indigenous materials. Of particular interest are boards made from bamboo, sawdust and miscellaneous wastes. The processes are briefly given below.

Bamboo boards.—Strips of bamboo are woven into mats of the required size. The mats are first dried to a moisture content of 8—12%, than dipped into, or brush-painted with, phenol-formaldehyde solution, and conditioned and pressed at 140° C at a suitable pressure. The board may be made of a single mat or with several mats pressed together. It has been found that satisfactory boards can be made with a resin content of 15% and a pressure of 28 kg per sq cm. The bamboo board is found to have excellent tensile and bending strength as also good water-resistance. It can

be made fire-resistant by using sand as a filler. By using sawdust as a filler irregularities on the surface can be removed. The single mat board has a modulus of rupture of 630 kg per sq cm and a tensile strength of 644 kg per sq cm. This has been found suitable for the blades of windmills. The bamboo board is also suitable for travelling requisites, furniture, etc. Boards have been produced in corrugated and hollow types. Hollow types are good for insulation, and are suitable for walls, flush doors, decking, etc. They can be faced with fancy veneers or metal sheets. The Imperial Chemical Industries have tested samples of bamboo board and declared them as very satisfactory.

Sawdust board.—Sawdust boards are normally made by using phenol-formaldehyde glue. In experiments conducted at the Institute, this resin has been dispensed with and boards have been made with cheap indigenous chemicals or other materials. The sawdust is activated either chemically or biologically and then pressed at high temperature and pressure. The activators used include polybasic organic acids, phenolic bodies, sulphur, carbon bisulphide, shellac, tamarind or other acid fruits, chir-pine needles, etc. The moduli of rupture of these boards vary from 280 to 560 kg per sq cm and the water absorption from 3.3 to 14.96%. They can be used as table-tops, knobs, handles, etc. The sawdust boards compare very favourably with similar type of boards and other building boards of reputed manufacture.

Other boards.—Boards have also been developed from waste containing tannin, e.g., tree barks, spent tea leaves, etc., by the addition of a small percentage of phenol-formaldehyde. Powdered barks of khair (*Acacia catechu*) and myrobolan (*Terminalia chebula*) mixed with hexamine, or hexamine and a small quantity of caustic soda, have been moulded into boards under suitable conditions of heat and pressure.

A method developed at the Institute consists in subjecting ligno-cellulosic wastes to a thermal treatment with water in an autoclave and then pressing the material into boards. Wood waste from khair (*Acacia catechu*), semul (*Bombax ceiba*), toon (*Cedrela toona*), white cedar (*Dysoxylum malabaricum*) tapioca (*Manihot esculenta*), chir (*Pinus roxburghii*) and mullilam (*Fagara budrunga*) and barks of *Araucaria* spp., *Euphorbia nivula*, *Erythrina suberosa*, etc., were used. Boards having a modulus of rupture of about 210 to 455 kg per sq cm and a water absorption of 3 to 30% have been produced by this process. The same process has been used for developing moulding powders from tapioca stem, hoop pine (*Araucaria* spp.) bark, areca-nut husk, teak sawdust, etc., for making boards.

Uses of particle boards

Particle boards have adequate strength for interior applications in housing or furniture. They are not usually recommended for use in exterior or other severely exposed conditions, because they shrink and swell appreciably. As the wood particles are compressed to more than their usual density during pressing, these boards are also subject to springback (thickness swelling) when moisture content changes occur in service; the springback may amount to 20 per cent in some products. When large panels in which the linear change will be appreciable have to be used, they need to be specially designed.

Adhesives Used in the Manufacture of Composite Wood

General

Besides its use in conventional wood-working, gluing is done extensively in the production of plywood, laminated wood and other forms of composite wood. In fact, it would not have been possible to develop the science and technology of composite wood to its present stage but for adhesives.

Modern glues, processes and techniques vary as widely as the products made, and represent a constantly developing specialized field which is outside the scope of this book. The various kinds of glues used in the industry will be briefly dealt with here.

Types of glues

Glues may be classified as follows :

(1) Animal glues.

(2) Casein glues.

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(3) Vegetable-protein glues.

(4) Vegetable-starch glues.

(5) Synthetic-resin glues.

(1) *Animal glues.*—These are made chiefly from hides, bones, sinews and hide fleshings of cattle. They are probably the oldest known glues, and are used in this country in large quantities by carpenters. The approximate annual production is about 100 tonnes, and there are about five factories in India. Their price, the importance of temperature control in their use, and their low water and micro-biological resistance have limited the used of animal glues in the composite-wood industry. Researches at the Forest Research Institute, Dehra Dun, and elsewhere have, however, enabled development of water-resistant animal glues.

Some liquid animal glues are made from the heads, skins, bones and swimming bladders of fish. Most of them have the limitations of other animal glues.

Glues are also made from the soluble blood-albumin of animals. They have shown notably high resistance to moisture, but their chief drawback has been the necessity for hot-pressing. Blood-meal adhesive showing satisfactory results have been developed at the Forest Research Institute, Dehra Dun.

(2) *Casein glues.*—These are made from the curd of soured milk, lime and other chemical ingredients. They have sufficient strength either for veneer or joinery work, and can be cold-or hot-pressed. Casein glues have generally been commended for their high water-resistance and suitability for gluing articles to be used in wet conditions, but there are casein glues that are not water-resistant. The manufacture of casein in the country is concentrated in Khaira District (Gujarat) on a cottage industry scale. The production before World War II, and even in more recent years, amounted to about 1,000 tons a year ; 80 per cent of the production was consumed by the plywood industry, but this has fallen substantially owing to the large-scale use of urea-formaldehyde glue.

(3) *Vegetable-protein glues.*—These resemble casein glues in their properties, and are made from the meal of soyabean, groundnut, and other vegetable produce with high protein content. The cost of casein rose up during World War II from Rs. 250 to Rs. 6,000 per ton, and therefore alternatives protein glues were looked for. As a result of investigations made at the Forest Research Institute, satisfactory cold and hot-setting glues were developed from the protein of groundnut and other cakes, rape seed, and seeds of sunn hemp, *Lathyrus sativus*, karar (*Sterculia urens*), *Albizia lucida*, *Aleurites montana*, etc. Water-resistant prolamin adhesives were developed from prolamin isolated from gluten. These were also developed in the form of a film. These developments brought down the price of casein to Rs. 2,000/- per ton.

(4) *Vegetable-starch glues.*—These are usually made from cassava starch. They are cheap and can be used cold, but are lacking in water-resistance.

(5) *Synthetic-resin glues.*—These were the products of later developments in the industry, and now surpass many of the older glues in importance. They are numerous, and include phenolic, urea, resorcinol, polyester, polyvinyl, epoxy and other glues. They are classified, broadly, under thermosetting and thermoplastic types. Thermosetting resins, once cured, are not softened by heat; thermoplastic resins will soften when heated again. Thermoplastic resins are now little used in the production of plywood, though they found extensive use in former days when techniques were still imperfect.

Synthetic-resin glues in general current use belong to two types, viz., phenolformaldehyde gluer and urea-formaldehyde glues. Generally, phenol-resin adhesives require simultaneous applications of heat and pressure (i.e. hot-pressing). The joints are characteristically of very high resistance to moisture and it is very difficult to destroy the joint without destroying the wood. The urea-formaldehyde glues can be used for hot-and cold-pressing. They are sufficiently durable under all but the most severe conditions.

Phenolic glues are widely used for making plywood that would stand severe service conditions. Urea-resin glues are used extensively for producing plywood for furniture and interior panelling. Resorcinol and phenol-resorcinol resin glues are used for gluing products that have to withstand exposure to weather. Polyvinylresin emulsion glues are used in assembly joints of furniture.

The Forest Research Institute, Dehra Dun, has carried out experiments on synthetic-resin glue and substitutes, and the following are among important results achieved :

(1) Urea-formaldehyde resin adhesives, stable in syrup form for a few months and comparable with foreign ones, have been developed.

2) Phenol-formaldehyde resin glues of excellent properties have been made from tar acids of Indian origin.

(3) Investigations of cresol-formaldehyde resins have indicated the possibilities of developing low-temperature adhesives.

(4) As phenol is not available in enough quantity, a search for substitutes for phenol-resin glues was made, and three promising ones have been developed from cashew-nut shell liquid, tannins and activated coconut shells.

Synthetic resin glues are still largely imported, though indigenous production with a capacity of 5,400 tonnes of urea-formaldehyde per annum has started.

IMPROVED WOOD

Definition

Improved wood is a general term for wood that has been specially treated in various ways to reduce or retard working (i.e., alternate swelling and shrinking) or to increase its strength. Treatment may involve impregnation with synthetic resins (e.g., Impreg) and other materials, and/or compression (e.g., Compreg), and/or heating (e.g., Lignostone), and may be applied to solid wood or to veneers that are subsequently bonded together. The term is *not* applicable to timber treated with preservatives or orthodox finishes such as a paint, or to plywood and similar products.

The treatments have the effect of modifying the properties of the wood in terms of hygroscopicity, working, density and strength, etc., and for this reason improved wood is also known as *modified wood.*

Types of improved wood

Depending on the treatment, improved wood may be classified as follows :

(1) Impregnated wood.

(2) Heat-stabilized wood (Staybwood).

(3) Compressed wood.

(4) Compregnated wood (Compreg).

(5) Heat-stabilized compressed wood (Staypack).

(6) Chemically modified wood.

Impregnated Wood

The term 'Impregnated Wood' is a collective name for woods impregnated with all possible impregnants (wax, paraffins, resins, oils, etc.) with the object of improving dimensional stability and preventing water absorption. The best known examples are 'Permali' made in France by impregnating beech with alcoholic phenoilic resin and 'Impreg' made in America and elsewhere by impregnating woods with synthetic resins.

Impreg.—The most successful impregnants that have been commercially applied are water-soluble, thermosetting, phenol-formaldehyde resin-forming systems. No thermoplastic resins that effectively stabilize the dimensions of the wood have been found. Veneers treated with a thermosetting, fibre-penetrating resin that is cured without compression, and then bonded together are known as *Impreg.* The veneers are soaked in the aqueous resin-forming solution or impregnated with the resin by vacuum-impregnation, with or without subsequent pressure, until the resin-content is equal to 25 to 35 per cent of the weight of the dry wood. They are allowed to stand under non-drying conditions for a day or two, to permit the uniform distribution of the solution throughout the wood. The resin-containing wood is dried at moderate temperatures to remove the water and then heated to higher

temperatures to set the resin. They are then coated with the same or any other resin and air-dried. The veneers are then assembled and pressed, using the same pressure as used in the case of plywood.

Uniform distribution of the resin has been effectively accomplished in the case of solid wood only in the case of sapwood of readily treatable species in lengths up to 1.8 m. The drying of the resin-treated wood also brings about checking and honey-combing. It is for these reasons that the treatments have to be confined to veneers and the cured veneers used to build up the desired objects. Veneers of all species, except the resinous pines, can be used. The stronger the original wood, the stronger will be the product. The resin-impregnation of solid wood is better-limited to small valuable specialities such as sports goods, brush-backs, lithograph backings and shoe-lasts.

By resin-treatment, the hygroscopicity and swelling and shrinking of the wood are reduced, and correspondingly the grain-raising and surface-checking. The wood also becomes resistant to decay and termite and marine-borer attack. Electrical resistance, as also resistance to most chemicals excepting alkalis, is increased. Compression strength, hardness and density are improved, but tensile strength and impact strength are reduced.

Impreg found limited use during World War II in panels for housings for special electrical control equipment. It can be used for facing exterior plywood in order to eliminate checking. It can also be used for master patterns, such as master shoe-lasts, in which dimensional stability is of major importance. It is suitable for patterns and die-models for automobile parts, for acid tanks and components in electrical equipment, etc.

Investigations have been carried out at the Forest Research Institute, Dehra Dun, on the impregnation of a number of Indian woods, e.g., babul (*Acacia nilotica*), kadam (*Anthocephalus cadamba*), *Erythrina suberosa*, *Moringa oleifera*, semul (*Bombax ceiba*), hollock (*Terminalia myriocarpa*), etc., with synthetic resins, paraffin, cashew shell oil, and other materials. The results vary with species, but the general indication was that the strength properties of inferior Indian woods can be improved by treatment with synthetic resins and other impregnants. The process is not expected to find application with solid timber of thicker sizes, but such materials as veneer or veneer mats can be profitably used for making impregnated wood.

Heat-stabilized Wood (Staybwood)

It has been found feasible to impart an appreciable degree of stabilization of dimensions and decay-resistance to wood by a simple heat-treatment which reduces the hygroscopicity. This entails, however, a reduction in the strength of the wood, particularly its toughness. The treatment consists in passing wood beneath the surface of a molten metal or fused salt, and thus subjecting it to controlled high temperatures from 260° to 315°C for a few minutes under non-oxidizing conditions. The product, known as *Staybwood*, is indicated for window-sash and windowframes, in which dimensional stability and decay-resistance are important and some strength can be sacrificed.

Compressed Wood

In this case the wood is compressed without impregnating it with any synthetic resins. Considerable improvement in the properties of wood can be attained by compression.

Compression across the fibre increases the specific gravity of wood and thereby improves its strength properties. Theoretically, it should be possible to compress wood to a specific gravity of 1.46 if no air space is left in it. In practice, pressures varying from 90 to 140 kg per sq cm are applied and materials varying in specific gravity from 1.2 to 1.3 are obtained.

Compressed wood can be made either from solid wood or from laminated wood. In Germany, compressed solid wood has been manufactured under the name 'Lignostone' and compressed laminated wood under the name 'Lignofol'.

Lignostone is manufactured by compressing beech (*Fagus* spp). from both sides across the grain simultaneously. It has good strength properties and high resistance to wear, and is smooth. For these reasons it is eminently suitable as a substitute for persimmon (*Diospyros* spp., mainly *D. virginiana*), cornel wood (*Cornus* spp., mainly *C. florida*), etc., for shuttles. It has also good elastic properties, and is used as a substitute for hickory (*Carya* spp,) and ash (*Fraxinus* spp,) for picking-sticks,

Lignostone is also used for door handles, bearings, rollers, vibrating or shaking troughs for collieries, snow-shoes, beading, etc. In electrical apparatus, it has found application in places where a material with greater strength than porcelain or bakelite is desired.

The Forest Research Institute has carried out investigations on compressing the wood of a number of Indian species. It has been found that even with inferior species like *Moringa oleifera* the wood is considerably improved by compression. The best results were obtained by compressing at 14% moisture content and at a temperature of 160°C. The experiments have indicated possibilities of utilizing compressed *Cryptomeria japonica*. A material similar to lignostone has been obtained from kanju (*Holoptelea integrifolia*).

Compregnated Wood or Compreg

Compregnated wood, or *compreg*, is wood that is both impregnated with synthetic resin and compressed. The timber is converted into veneers, and the veneers are compressed together in a pack at a suitable pressure and temperature after impregnating them with phenol-formaldehyde resin. The resin treatment prior to compression improves the compressive property and shear strength of the wood in a plane at right angles to the direction of compression. By suitable choice of wood, thickness of veneer, pressure, temperature and direction for laying the veneers, the properties of the resultant material can be varied and made to suit particular requirements. The term "compreg" is commonly applied to material compressed to a specific gravity of 1.3 to 1.4

The process results in high dimensional stability ; shrinkage or swelling with atmospheric changes becomes negligible. The compression increases the tensile strength, modulus of rupture in bending and modulus of elasticity in direct proportion to its extent. The impregnation of resin, however, reduces the impact strength. Compreg is highly resistant to mild acids, alcohols and many other solvents. It takes on a high lustre from the press-platens and needs no further finishing. Since the resin permeates the whole panel, surface scratches or marks may be sanded or burnished out without additional treatment. Compreg has 10 to 20 times the hardness of normal wood and has increased wear-resistance. It has satisfactory electrical properties for insulation purposes. It has a high heat-resistance. It is also highly resistant to decay, termite and weather conditions.

Compreg is an excellent material for aeroplane propeller blades. It is suitable for gear wheels, bearings (for rolling mills, textile mills,etc.), fish-plates, press forms, textile- mill accessories, electrical machinery, etc. On account of its combined load-bearing and thermal-insulating properties, it is useful as supporting blocks for refrigerators. Other household uses are : knife-handles, trays, fan blades, instrument cases, electrical insulation, facing material for floors, trailer panels, interior panels, furniture, sanitary fittings, etc. Floors using compreg look very attractive and remain excellent after years of service. Compreg shows best promise for future use as facing material for ordinary plywood, particularly for external use in houses, boat-siding, etc.

Investigations have been carried out at the Forest Research Institute, Dehra Dun, on compregnating a number of indigenous species, e.g., salai (*Boswellia serrata*), toon (*Cedrela toona*), deodar (*Cedrus deodara*), mullilam (*Fagara budrunga*), mango (*Mangifera indica*), spruce (*Picea smithiana*), devdaru (*Polyalthia fragrans*), semul (*Bombax ceiba*), hollock (*Terminalia myriocarpa*), etc. It has been found that compreg of suitable properties can be made in this country. Mullilam yields a compreg of high impact strength. Even inferior timbers like salai and semul yield compreg of good properties. During World War II, compregnated semul was used by the Royal Air Force in place of the conventional compreg from birch (*Betula* spp.). Compreg made at the Institute has been tried with satisfactory results for shuttles, printing blocks, furniture, fish-plates, end-posts in electrical railways, bearing plates for sleepers, tube-well buckets, bearings for river-barges, etc. During the War it found wide application as tooling jigs and dies, enabling diversion of metal for other purposes.

Heat-Stabilized Compressed Wood (Staypak)

Both impregnated wood and compregnated wood are more brittle than the original wood. To meet the demand for a tougher product, a compressed, solid or laminated wood without impregnation with resin has been developed. This is called *Staypak*, and is made by modifying the compressing conditions so as to cause the lignin cementing material between the fibres to flow sufficiently to eliminate

the internal stresses. The wood is compressed to a specific gravity of 1.3 to 1.4. Both solid and laminated wood can be made into staypak. When made out of veneers, the veneers are painted with just sufficient resin-glue for bonding and then pressed at suitable moisture content and pressing conditions.

Staypak is not as water-resistant as compreg, but is about twice as tough and has higher tensile strength, modulus of rupture and modulus of elasticity. The natural finish of staypak is almost equal to that of compreg. It is however, inferior to compreg under weathering conditions, and for outdoor use needs a good varnish of synthetic resin.

Staypak can be used in the same way as compreg where extremely high water-resistance is not needed. It shows promise for use as propellers, spar plates, toolhandles, mallet heads, pulleys, silent gears, tool jigs, forming dies, picker-sticks, shuttles, etc., which require high impact strength.

Manufacture of staypak has received detailed investigation at the Forest Research Institute, Dehra Dun, with indigenous species, e.g., haldu (*Adina cordifolia*), alder (*Alnus nitida*), palas (*Butea monosperma*), white dhup (*Canarium strictum*), casuarina (*Casuarina equisetifolia*), toon (*Cedrela toona*), gurjan (*Dipterocarpus* spp.), white cedar (*Dysoxylum malabaricum*), mullilam (*Fagara budrunga*), fig (*Ficus glomerata*), walnut (*Juglans regia*), mango (*Mangifera indica*), malabar neem (*Melia composita*), kaim (*Mitragyna parvifolia*), chir (*Pinus roxburghii*), semul (*Bombax ceiba*), *Sapium sebiferum*, etc.

Chemically Modified Wood

As the hygroscopicity of wood is attributed to the hydroxyl groups in cellulose, attempts have been made to make wood less hygroscopic by the replacement of these groups with less hygroscopic groups, simultaneously bridging the structural elements in order to reduce their tendency to separate. *Acetylated wood* is a product of such a treatment. Acetylation can be done by heating dry wood with acetic anhydride in the presence of pyridine as catalyst. It results in reduced hygroscopicity and shrinkage and swelling. The stabilization thus obtained depends on the degree of acetylation. A minimum of 30 per cent acetylation is necessary for satisfactory dimensional stabilization. Methylation and allylation are similar processes for imparting dimensional stability to wood.

Of other forms of chemically modified wood that have been developed, mention may be made of *uralloy* (urea-plasticized wood) obtained by treatment of wood with urea, and *hydroxylin* (acid-hydrolysed wood) obtained by treatment with dilute sulphuric acid. These have specific advantages over ordinary wood, but do not appear to have reached the stage of extensive commercial application (Varossieau : 1954).

REFERENCES

Anon	1950	Notes on the manufacture of flat plywood; U.S. Deptt. of Agriculture Forest Service, Forest Products Laboratory, Madison.
Anon	1950	Forestry Terminology—A Glossary of Technical Terms; Society of American Foresters, Washington.
Anon	1954	Indian plywood industry, IV World Forsetry Congress, Dehra Dun; Plywood Manufacture Association of India
Anon	1957	British Commonwealth Forest Terminology, Part II; Empire Forestry Association, London.
I. S. I.	1949	Tentative Indian standard specification for plywood-tea-chests, IS : 10-1949; Indian Standards Institution, Delhi.
I. S. I.	1951	Specification for commercial and moisture-proof plywood, IS : 303-1951; Indian Standards Institution, Delhi.
I. S. I.	1955	Logs for plywood, IS : 656-1955; Indian Standards Institution, Delhi.

Dietz, A. G. H. & O'Neill, A. J.	1954	Composite wood *Composite Wood*, **1** (2); Dr. D. Narayanamurti, Dehra Dun.
Harrar, E. S.	1947	Veneers and Plywood, their manufacture and use; *Econ. Bot.*, **1** (3); The New York Botanical Garden for the Society for Economic Botany, Maryland.
Kapur, S. N.	1942	Note on the manufacture of plywood in India; *Indian For. Rec.* (N.S.), **2** (11), Utilization; Manager of Publications, Delhi.
Knight, E. V. & Wulpi, M.	1927	Veneer and Plywood; Ronald Press, New York.
Kraemer, Otto	1955	Improved wood; *Composite Wood*, **2** (5); Dr. D. Narayanamurti, Dehra Dun.
Narayanamurti, D.	1957	Wood waste utilization; *Indian For. Bull.* (N.S.), No. 207, Composite Wood; Manager of Publications, Delhi.
Narayanamurti, D. & Bist, B. S.	1963	Building boards from bamboos; *Indian For. Rec.* (N.S.), **1** (2), Composite Wood; Manager of Publications, Delhi.
Narayanamurti, D. & Singh, J.	1954	Studies on building boards, Part VI; *Composite Wood*, **1** (4); Dr. D. Narayanamurti, Dehra Dun.
Panshin, A. J., Harrar, E. S., Bethel, J. S. & Baker, W. J.	1962	Forest Products, their Sources, Production and Utilization, 2nd Edition; McGraw-Hill Book Company, New York.
Perry, T. D.	1944	Adhesives; Pitman, New York.
Perry, T. D.	1948	Modern Plywood, 2nd Edition; Pitman, New York.
Varossieau, W. W.	1954	Forest Products Research and Industries in the United States; J. M. Meulenhoff, Amsterdam.
Williston, E. M.	1958	Fibre Board and Particle Board, **1-6**; F.A.O., Rome.
Wood, A. D. & Linn., T. S.	1943	Plywoods, their Development, Manufacture and Applications; Chemical Publishing, New York.

CHAPTER XVI
WOOD PRESERVATION

Introductory

The object of the science and practice of wood preservation is to prolong the life of non-durable wood. With the passage of time, all building materials deteriorate during service; steel rusts and corrodes, brickwork or concrete disintegrates, and wood is destroyed by the action of fungi, insects, marine borers and fire. Thus the forces of nature are too strong for any building material to resist permanently without eventually disintegrating, and timber is no exception.

Timber offers many advantages like abundant supplies from renewable resources, electrical insulation and sound absorption properties, high salvage value, low cost, low weight, low thermal conductivity, ease of working, high strength value (weight for weight) as compared to other constructional materials, and amenability to improvement of its natural properties and elimination of its disadvantages by modern processes. Wood however, being a biological product, is liable to deterioration unless it is properly protected. The chief causes of deterioration or destruction of timber in service are decay (due to fungal infection), attack by insects (borers and white ants), marine organisms and fire. Decay and damage by white ants are by far the most important factors in the deterioration of timber in service in India. Wood preservation is the art of preserving timbers against the agencies of deterioration.

Natural durability of wood

By natural durability is meant the inherent ability to timber to resist decay and other destructive agencies. In its natural State, sapwood of all timbers is non-durable, while the heartwood of only a few species of timbers is durable. Natural durability, therefore, conveys the idea of the extent of the durability life of the heartwood portion only. Data on the natural durability of 235 species of timbers tested in the 'graveyards' at the Forest Research Institute, Dehra Dun, are given in Appendix IV. For obtaining these results, six heartwood stakes, 60 cm × 5 cm × 5 cm, of various species were buried in the yard in the open up to half their height, and their resistance to attack by insects, termites and fungi determined over a period extending to several years. The following categories of durability are used for purposes of classification of timbers by the Forest Research Institue, Dehra Dun.

Class of durability	Category	Approximate service life in years
I	Durable	More than 10
II	Moderately durable	5 to 10
III	Non-durable	Less than 5

Also, data on 53 species of timbers with respect to their fire resistance as determined in the laboratory is given in Appendix V.

Need for preservative treatment

The primary objective of preservative treatment is to increase the life under service conditions of such treated material. Experience has shown conclusively that, with suitable chemical treatment, the life of timber can be increased to 5-10 times its normal life and its fire-resistive property to 2-3 times the normal. Prophylactic treatment should also be given to timber and bamboos to protect them for a period of three to six months, during transit and storage, prior to full-fledged preservative treatment. Timber can also be chemically treated to protect it from fungi causing blue, brown, etc., stains which lower the market value of the timber. Thus wood preservation helps in the proper utilization of timber and in the conservation of timber resources and forests.

It is common knowledge that certain species of timber like teak, sal and deodar are universally utilised for building construction. The special preference for these timbers is due to their naturally durable heartwood. However, the supplies of these naturally durable timbers are limited and are inadequate to meet the growing demands of an increasing population or industry. It is, therefore, imperative to use secondary species after suitable preservative treatment. A table giving a list of such timbers is given in Appendix VI.

In all advanced countries of the world, timber preservation is invariably done as a standard practice. Statistics of the life of treated timber (especially non-durable species) show that by treatment a life 4-5 times that of untreated timber can be expected in the open, and 7-10 times or more in inside locations. In the U. S. A., an average life of 20-25 years has been obtained for railway sleepers. In India also an average life of 20-25 years is obtained for treated sleepers of chir, laurel, hollock, hollong and jarul. There are many other species which are suitable for sleepers after treatment. In a similar way, fence posts, transmission poles, piles and bridge and building timbers can be protected by preservative treatment.

Scope for wood preservation in India

The scope of wood preservation in India lies mainly in the treatment of timbers to be used for the following purposes :

(1) *Railway sleepers.*—The Railways have been pioneers in adopting wood preservation method for protecting wooden sleepers. Properly-treated wooden sleepers have given an average life of 20-25 years. Preservative treatment permits the use of unlimited quantity of sapwood in sleepers as sapwood can be very satisfactorily preserved by treatment. Supply of sleepers can be augmented by using treated half-round and waney sleepers, as more sleepers of this type can be turned out from the same log as compared to rectangular sleepers, and it is easier to preserve them due to their high sapwood content.

(2) *Transmission poles, telegraph and telephone poles and piles.*—Experience has shown that wooden poles for the above purposes are by far the best material from the point of view of economy and convenience. A properly treated wooden pole can be expected to give a service life of 25 years or more even under adverse conditions. At the Forest Research Institute, Dehra Dun, such treated poles are intact even after 28 years of service.

(3) *Timber for other constructional purposes.*—A large quantity of timber, bamboos, palmyra and grasses is required for house-building purposes. It is possible to treat beams, window and door frames, ceiling timbers, shingles, and paving blocks, and get a life of 60-70 years under favourable conditions and 40-50 years under adverse conditions.

(4) *Packing-cases and furniture.*—The demand for packing-cases has enormously increased of late. Timbers of low durability and plywood are normally used for this purpose. Their life can be considerably increased by proper preservative treatment and shortages of these materials can be overcome. Low-grade timbers, after preservative treatment, can be used for furniture, etc., and expected to give good service life.

Chief characteristics of a wood preservative

The chief characteristics of an ideal wood preservative are :

(1) high toxicity (high lethal effect even in low concentration) against fungi and/or insects and/or marine organisms;

(2) high permanency under all service conditions, i.e., resistance to bleaching by water or to rapid evaporation due to heat, or chemical transformation due to oxidation, reduction, polymerization or chemical or enzymic action causing reduction in toxicity;

(3) high penetrability, i.e., amenability to impregnation over the entire cross-section of the wood to be treated; and

(4) high stability during treatment, i.e., resistance to decomposition at temperatures normally used during treatment and to precipitation due to reducing action of chemical in timber.

Further the preservative :—

(1) should not increase unduly the inflammability of wood, but in fact should tend to increase the natural resistance of timber to fire;

(2) should not impair the health of the labour during treatment, of the workmen during assembly of treated timber, or of the residents of a house either while in occupation or in a fire accident, when treated timber is used in the construction;

(3) should be economically cheap and commercially available from indigenous sources in uniform degree of purity;

(4) should be capable of being transported to distant places and high altitudes without excessive charges;

(5) should not corrode metals used in the manufacture of treating equipment, or metals used along with treated timber during actual service ;

(6) should allow treated timber to be painted over or varnished; and

(7) should not reduce the strength of timbers to be treated.

It is not always possible to obtain such an ideal preservative, but care is necessary before a compromise is made and a suitable preservative is chosen for any particular use, the deciding factor being proven service efficiency.

Varieties of preservatives

There is a large variety of preservatives available for wood preservation purposes. These fall under four main types.

(i) Oil type—Tar oils
(ii) Water-soluble leachable type
(iii) Water-soluble fixed type
(iv) Organic solvent type

These are detailed below.

(i) *Oil type—Tar oils*

This type comprises various forms of creosote and is at present the most important for posts, poles, piles, mine timbers and sleepers. A very large percentage of all preservative treatments given in India use creosote, which is derived as a coal-tar by-product of coke and steel industries. No other preservative has so far proved more satisfactory than creosote, where the odour, colour and "bleeding" of the latter is not objectionable.

There are many different types of creosotes used for preservative treatment, such as coal-tar creosote, wood-tar creosote, and water-gas-tar creosote. The best and most widely used creosote of established reputation is the coal-tar creosote, which is obtained by distillation of coal-tar, with boiling point between 210 °C and 355 °C. For wood preservation, this may be used in admixture with petroleum fuel oils in the ratio of 50 : 50 by volume/weight. While fuel oil as such has practically no toxic properties, its presence in the mixture to the extent of 50 per cent by weight ensures stability to the creosote against evaporation and leaching from the treated timber. In addition, admixture of oil gives a certain amount of protection to timber against splitting and cracking. It mixes with creosote in all proportions, and on account of its cheapness it is economical to use in admixture with creosote. Creosote is not suitable for use as regards timber for dwellings where its odour and colour are objectionable, and its defects such as tackyness and unpaintability over treated timber surface are serious drawbacks. Solignum and Creosant are two proprietary preservatives containing high-boiling creosote as a base and these are used for brush treatments.

(ii) *Water-soluble leachable type*

These comprise inorganic or organic salts soluble in water. Among these may be mentioned zinc chloride, zinc sulphate, copper sulphate, boric acid, borax, sodium fluoride, arsenic trioxide, arsenic

pentoxide and sodium penta-chlorophenate. Most of these have no objectionable odour or colour and are introduced in an aqueous solution. They are easy to transport and are odourless, except for sodium pentachlorophenate, and involve little fire hazard. Timber treated with these preservatives can be painted or varnished when dry. These preservatives, however, are subject to leaching, i.e., the amount of preservative in the treated timber gets gradually depleted owing to the dissolving effect of water. The leaching of the preservative can be minimised if a further water-proof paint coating is applied and is periodically renewed.

(iii) *Water-soluble fixed type*

These comprise mixtures of various water-soluble salts described above with the addition of a fixative salt, usually sodium or potassium dichromate. The effect of chromium is to fix the toxic ion—arsenic, copper, zinc, etc.—in the wood, so that it is not easily leached by the action of water. It is, however, necessary that the treated timber should be allowed to dry for 3-6 weeks to complete the fixation process. Such treated timber, therefore, can be used for outside locations and, unlike creosoted timber, can also be painted over. These preservatives are applied cold as they are liable to get precipitated when heated, due to interaction with certain wood constituents.

Typical preservatives under this category include ;

(i) Arsenic-copper-chromate (arsenic-pentoxide, copper sulphate and sodium dichromate in the proportion of 1 ; 3 ; 4);

(ii) Acid-cupric-chromate (50 parts of copper sulphate, 47.5 parts of sodium dichromate and 2.5 parts of chromic acid or chromium acetate);

(iii) Chromated-zinc-chloride (zinc chloride and sodium dichromate in the proportion of 1: 1)

(iv) Copper-chrome-boric composition (boric acid, copper sulphate and sodium dichromate in the proportion of 1.5 : 3 : 4);

(v) Zinc-meta-arsenite (arsenious troioxide and zinc oxide in the ratio of 3 : 2, and sufficient acetic acid to keep the zinc-meta-arsenite in solution under operating conditions) ; and

(vi) Zinc-chrome-boric composition (boric acid, zinc chloride, sodium dichromate and water in the ratio of 1 : 3 : 4 : 100).

Proprietary fixed preservatives of some of the above types are available in the market under the name of Ascu, Celcure, Boliden salts, etc.

(iv) *Organic solvent type*

These consist of copper and zinc salts of organic acids such as naphthenic acid, stearic acid and abietic acid, etc., and chlorinated phenols and benzenes like pentachlorophenol, dieldrin, benzene hexachloride, and DDT. These are used after dissolving them in suitable organic solvents (like solvent naphtha, and petroleum products such as kerosene and white spirit) of low boiling point, so that when the treated timber dries up the solvent evaporates off leaving the preservative behind. The preservatives are clean to handle and are permanent. They are insoluble in water; hence wood, once adequately impregnated, loses little of the preservative through leaching and may remain in exposed situations with relative immunity to stain, decay and termite attack. 'Hardiproof' and 'Cuprinol' are two proprietary preservatives of the above type containing copper naphthenate as a base. Timbers treated with the above preservatives can be painted and varnished, and as such these can be used for brush-painting household furniture, tool handles, etc.

As some of the solvents are inflammable, care is necessary in handling the solutions, and the preservatives should be applied cold.

METHODS OF APPLICATION OF PRESERVATIVES

General principles

The main object of all treatment processes is to get adequate quantity and uniform distribution of the preservative inside the timber, consistent with the desired service life and economic advantages

to be obtained as a result of treatment. There are several methods of applying preservatives, some of which are undoubtedly superior to others; and each method has certain advantages which make it suitable under a particular set of conditions. The three principal methods of application are : (i) surface application, including painting and spraying ; (ii) dipping, steeping and diffusion, including the hot and cold and the Boucherie processes; and (iii) pressure processes. The first treatment covers only the surface of timber with the preservative, and in the the case of the second and third, except for dipping, the other treatments may result in deeper penetration and, in some cases, complete penetration of the preservative in the sapwood and also heartwood portions. Superficial treatments are cheaper than impregnation treatments and a minimum of equipment is required. Their use is justified under conditions where only a short added period of service life is required under exposed conditions, or when the treated timber is used under cover as furniture or for prophylactic purposes only.

Certain fundamental principles apply to all the three methods. Depth and uniformity of penetration are essential. They are dependent largely on the anatomical structure of the wood : sapwood absorbs preservatives more readily than heartwood; timber of some species is more readily penetrated than others. Depth of penetration is all the more important where checks and splits are likely to develop after treatment. However, wood below the treated skin is bound to get exposed sooner or later and hence treatment up to an optimum depth is desirable. Better penetration is obtained with hot then with cold methods of application excepting the diffusion process. Care should be taken where the preservative chemicals decompose on heating.

The amount of preservative retained in the wood is usually expressed in terms of the number of kg per cu m of wood.

Preparation for treatment

(i) *Bark removal.*—The bark, including the inner bark, must be throughly removed before treatment, except in the case of the Boucherie process.

(ii) *Seasoning and conditioning.*—Except with Boucherie and diffusion methods, wood should be seasoned or conditioned before treatment. The usual procedures are air-seasoning, kiln-seasoning, conditioning by steaming and vacuum, boiling in preservative oil under vacuum (Boultonising) and vapour-drying (wood surrounded by hot vapours). Moisture content should be below 25%. Air-dry wood is more absorbent than green wood. Treatment after seasoning or conditioning will also ensure that any checking will occur before and not after treatment thereby avoiding exposure of the wood beneath the treated shell.

(iii) *Machining.*—Cutting to final dimensions, adzing, framing, boring of holes, etc., should be completed prior to treatment. As sapwood has better absorptive capacity, it should be retained wherever possible; in larger-sized timbers, those with complete outer layer of sapwood should be preferred to those with heartwood on one or more faces.

(iv) *Incising.*—In the case of timbers whose heartwood is non-durable and refractory to treatment, incisions of all the surfaces, other than the ends, to a depth of 12 to 20 mm is necessary to ensure proper penetration of the preservative.

Treatment

This will be dealt with under the different methods already mentioned.

Surface application.—This may be done by brush or spray. This is the simplest method, but is also the least efficient. For this reason, this method should be used where other methods are not practicable, with highly penetrative preservatives and with timber of high absorptive properties. If second coat of preservative is to be applied, this should be done after the first coat has just dried up Where practicable, the treatment should be given hot. With the oil type of preservatives the moisture content of wood should be reduced to 10—14%. With aqueous solutions, however, it is permissible to have a moisture content up to 20—30%

Surface application has only limited scope and efficacy. When two or more coats are given and the treatment is repeated at intervals of two or three years, some measure of protection is achieved, particularly with wood work in interior locations.

The advantages of the surface application method are that it is cheap and rapid. The only drawback is its low efficiency, on account of allowing insect attack and decay to enter subsequent checks and places where the surface has been injured in handling.

Dipping.—This is also a superficial treatment, and consists in dipping or submerging the wood for a short period in the preservative. Dipping or immersing the timber in the preservative is better than spraying or brush-painting, because the wood is in contact with an excess of preservative for the duration of the treatment. Hot dip is preferable to cold dip for seasoned timber. This requires a vat large enough to permit submersion of the wood and arrangements for heating the preservative. For treating large quantities, this process is cheaper than brush treatment. If also gives more efficient results, as there is greater certainty of the preservative flowing into all checks and cracks. The disadvantages of this method of preservation are : at best only a slight penetration is secured, a tank is required and a large quantity of the preservative is necessarily left over after the completion of treatment.

Steeping treatment.—As the name implies, this treatment consists in steeping the wood in a preservative solution, usually at atmospheric temperature, for a long period. This is superior to a brush or dip treatment, but is not always as satisfactory as open-tank or pressure treatment. When corrosive sublimate ($HgCl_2$) solution is used, this process is known as *Kyanising.* Since recently, oil solutions of pentachlorophenol, copper naphthenate and zinc naphthenate are also used with season wood. The process requires only a tank large enough to permit submersion of the wood and equipped with a simple device to prevent floating. For posts requiring only treatment up to 15 cm above the ground line, a drum or barrel is adequate. The duration of the treatment varies according to the species of wood, its moisture content, sapwood and heartwood content, etc., and the absorption required.

Diffusion treatments.—In diffusion treatments, toxic water-soluble preservatives are used and they depend upon the ability of the toxic ion, when applied to the surface of green or wet timbers, to duffuse into the water contained in the green wood. Such treatments are particularly useful in the case of refractory woods where other treatments are not feasible. If the timber is green and is submerged in a water-soluble preservative for a long period—3 to 12 weeks depending on the size of the timber—the preservative gradually penetrates into the timber by molecular or ionic movement on account of the relatively high concentration of the preservative outside. A diffusion process, in which the green timber is coated with a preservative paste and, to prevent loss of moisture, immediately covered lightly with some water-proof material for periods of one to three months, is called *Osmose process.* The original process was intended for the treatment of individual pieces of timber, by wrapping round the timber a fabric bandage carrying or enclosing water-soluble preservative salts. This may be termed "Bandage Treatment", and is suitable for application to timbers *in situ,* such as fence posts, telegraph poles, mining timbers, etc. Powell process (*Syn. Powellizing process*) is a diffusion process in which the timber is immersed in a sugar solution containing arsenic trioxide. For treating posts *in situ,* the salt in a granular form can be mixed with the soil in contact with the post. Gradually the salt dissolves in the moisture and diffuses into the wood. Care is to be taken that the preserative is not washed off the soil by water or rain during the treatment period.

Hot and cold process (*Open-tank treatment*).—A modification of the dipping and steeping methods, known as the *Open-tank process,* gives more satisfactory results. It consists in placing the timber to be treated, wholly or in part (as in the treatment of the butts of fence posts and telegraph poles for which this method is especially suited), in a tank of the preservative fluid heated to a suitable temperature, and then allowing the timber to cool in it. This is widely practised in various forms (Fig. XVI-1, 2 & 3). It gives results comparable with those obtained with pressure processes, provided the timber allows easy penetration and absorption, but the treatment takes a longer time.

In this process, the timber is submerged in the preservative fluid which is then heated up to 90°—95° C, depending on the type of preservative and the species, size, moisture content and absorptive power of the timber. The temperature is maintained for 2—4 hours, till the charge attains the temperature of the bath. It is then allowed to cool down to the atmospheric temperature, or some temperature

higher than that, determined mainly by the required absorption of the preservative. During the heating period the moisture and the air in the timber are partially expelled; during the cooling period the residual moisture and air in the timber contract, thus creating a partial vacuum under which the preservative is sucked in. In this way, larger amounts of preservative are taken up by the wood, and penetration to a greater depth is obtained than by simply dipping the timer in either hot or cold preservative.

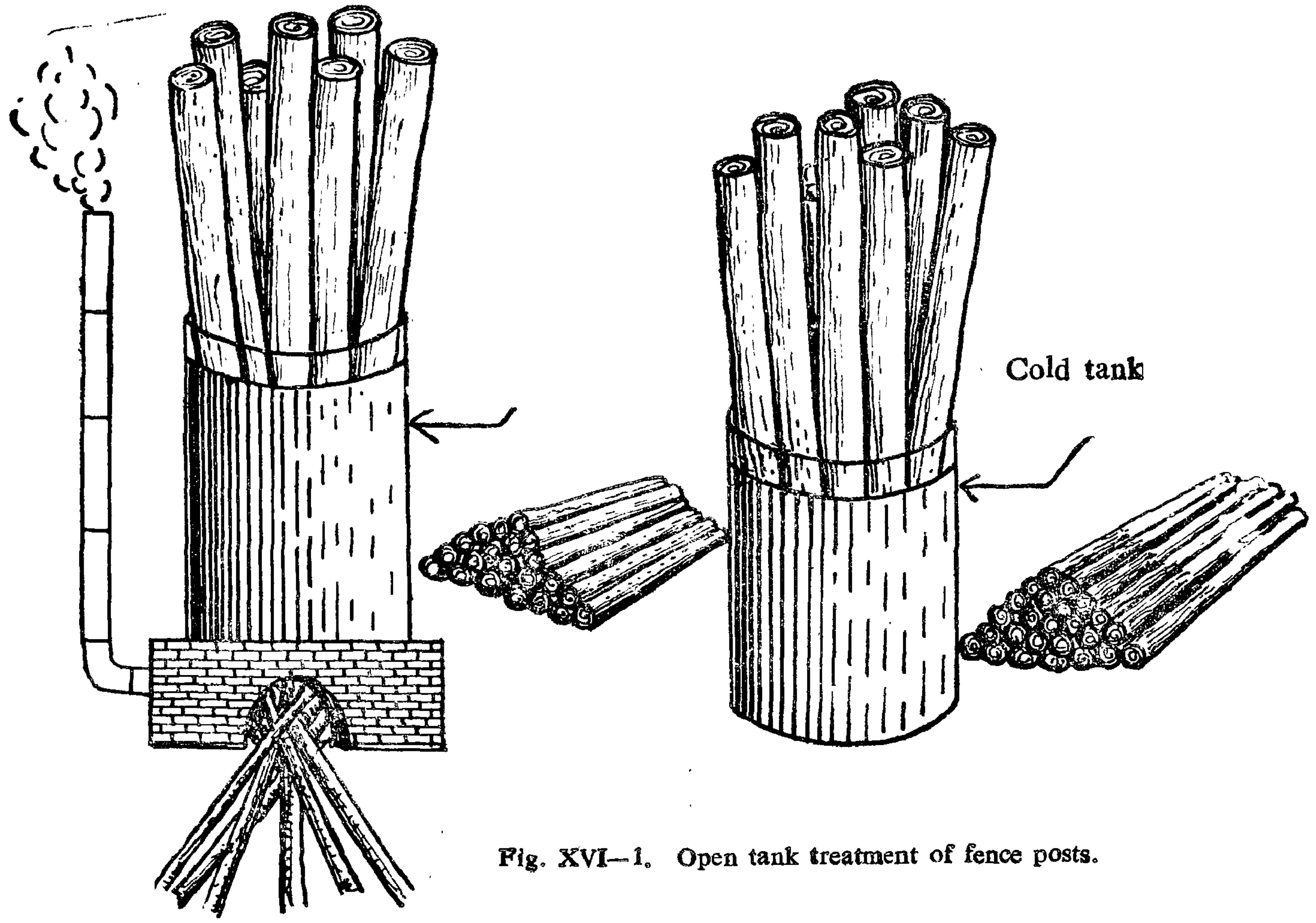

Fig. XVI—1. Open tank treatment of fence posts.

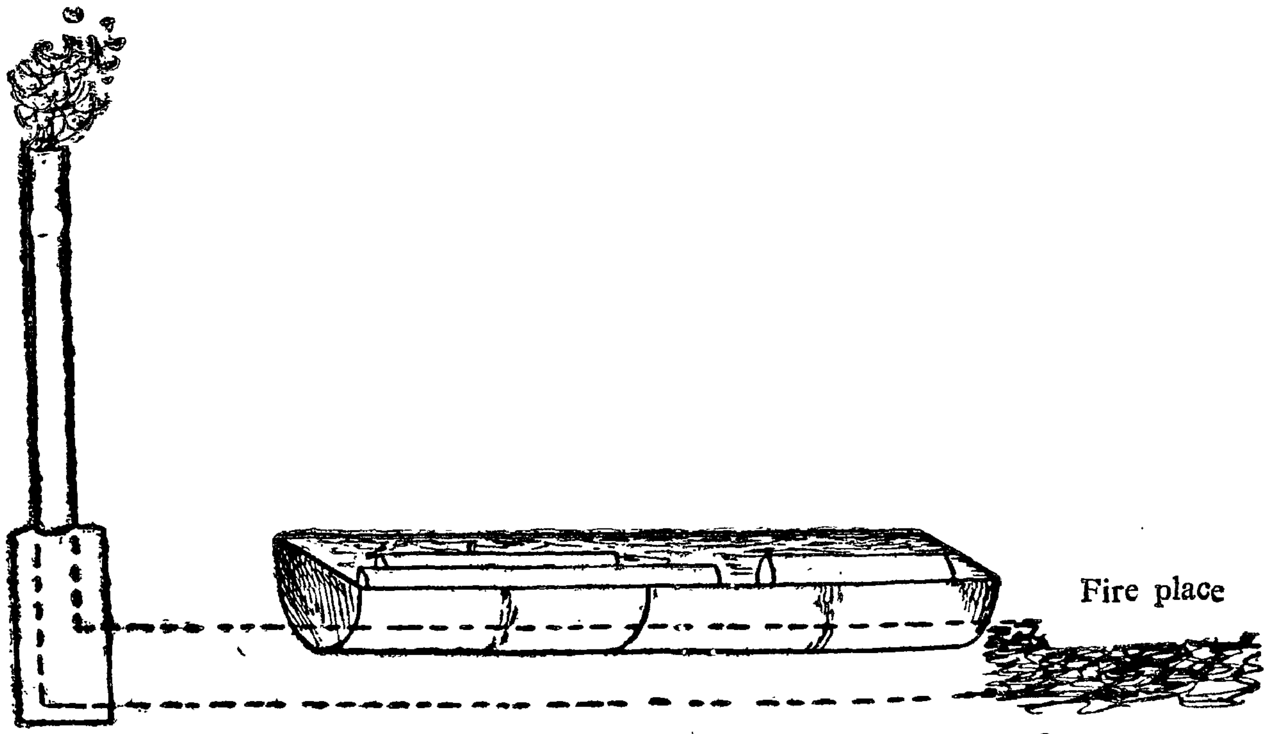

Fig. XVI—2. Hot and cold process. Direct heating by external fire.

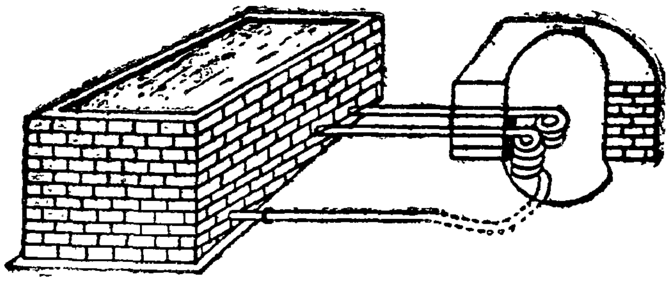

Fig. XVI—3. Hot and cold process. Indirect heating with steam-heated coils.

The treatment also ensures sterilization of the timber from any decay organism or insects that may be present originally. In the absence of facilities for pressure treatment, this process is recommended for timber containing sapwood or easily treatable heartwood. With inorganic fixed type of preservatives, however, there is a danger of precipitation of the chemicals at high temperatures and in contact with the reducing materials in timbers. To overcome this difficulty two baths are used, the first containing water where the hot treatment is given and the second, the cold bath, containing the preservative to which the timber is transferred immediately thereafter.

The simplest form of open tank is a container that can be heated by external firing (Fig. XVI-2)., but, because of the risk of the preservative catching fire, steamheated coils inside the tank are to be preferred (Fig. XVI-3). A simple type of semi-circular tank can be prepared easily by cutting length-wise several old galvanised oil drums, joining them together and suitably welding them. Recently an equipment has been designed at Forest Research Institute, Dehra Dun, wherein a light vacuum and/or pneumatic pressure can be applied over an open tank by providing a light fitting lid over it, in order to hasten the process of treatment. Cement tanks with indirect heating arrangement can also be used.

Boucherie process.—With the Boucherie process, treatment of bamboos and of the sapwood of all timbers with bark on, while in a green condition, can be done by using any of the inorganic water-soluble preservatives. The butt-end of the timber with bark on is held in an inclined position (preferably 45° to the ground) and attached to a reservoir containing the preservative at a higher level (Fig. XVI—4). In the case of bomboos, the basal internode is made use of as the reservior and, since the inner surface of the bamboo is not permeable, it is incised nearest the septum of the node used as the reservoir. The bamboo is held in a vertical position. The Boucherie process has not gained commercial success so far in India.

In recent experiments conducted at the Forest Research Institute, Dehra Dun, air pressure of 1.06-2.11 kg/sq cm (15—30 lb/sq in) has been used over the preservative in the original Boucherie method of treating green timber and bamboos (Fig. XVI-5 & 6). These air pressures are intended to ensure better and quicker penetration and absorption of the preservative and, particularly, to eliminate the unwieldy method of applying hydrostatic pressures involving the raising of the log or bamboos or the reservoir several meters above the ground

Pressure processes

The several treatment processes described above, namely surface application, dipping steeping, diffusion, and open-tank treatments, come under the category of non-pressure treatment as opposed to pressure processes, in which treatment is effected by forcing the preservative into the wood by pressure and/or vacuum applied in a closed vessel or cylinder. With pressure processes, penetration is obtained in resistant species of timber to a much greater depth than is possible by any other method. Also greater control is secured on the absorption of the preservative in the timer.

The pressure plant essentially consists of a mild-steel cylinder fitted with a door which can be hermatically sealed, a supply of steam for raising temperature, pressure/vacuum pumps for controlling the air pressure or vacuum inside, and an hydraulic pump for creating liquid pressure. The two main types of pressure processes are full-cell and empty-cell process. These are described below.

(i) *Full-cell or Bethel process*

This process is used when the highest volumetric absorption of preservative is desired. The timber charge is introduced into the cylinder and the door closed. A vacuum of at least 56 cm of mercury

column is created and maintained for half an hour or so. The object of this operation is to remove as much air as possible from the wood cells. At the end of the vacuum period the preservative is introduced into the cylinder, with the vacuum-pump working. When the cylinder has been filled with the preservative, the vacuum-pump is stopped and the cylinder is subjected to an antiseptic pressure of 3.50 to 12.30 kg per sq. cm. (50 to 175 lb per sq in.), depending on the species, size, refractory nature of timber, etc. This is done by continuously pumping the preservative liquid into the cylinder till the desired pressure is attained. This injects the preservative into the timber. The pressure is held until the desired absorption is obtained, after which the preservative is withdrawn from the cylinder, and finally a vacuum of 38 to 56 cm mercury column for about 15 minutes is once again applied to free the timber from the dripping excess preservative. Specified retention of toxic chemicals in the timber during treatment can be had by a proper selection of the concentration of the toxic material in the treating solution, and by a judicious control of the absorption of the preservative solution which can be regulated by the duration of pressure and vacuum periods.

This process and all its modifications are known as the "full-cell" process, because, if completely successful, not only is the preservative injected into the cell walls but the cell cavities also are filled with it. The process can be used with advantage for timbers of low absorptive properties and with readily leachable preservatives.

(ii) *Empty-cell processes*

These aim at a maximum penetration of the preservative with a minimum of net absorption, leaving the cells free of the preservatives (unlike in the full-cell process), and hence the name 'open-cell', or 'empty-cell' process. They are commonly known as the Lowry and the Rueping processes.

(a) *Lowry process.*—In this process the cylinder is loaded with timber and closed. It is then filled with the preservative, entrapping air in the cells at atmospheric pressure; an antiseptic pressure of 3.5 to 12.5 kg. per sq cm (50 to 175 lb per sq in.), depending on timber species, size, etc., is applied until the required absorption is obtained. The pressure is then released, when a certain part of the preservative injected into timber and compressing the air in the cells is expelled due to the expansion of the entrapped air in the cells. The cylinder is then drained off and finally a vacuum is applied as described above.

(b) *Rueping process.*—In this process the timber is charged into the cylinder, which is then closed. An air pressure of 1.75 to 5.0 kg per sq cm (25 to 75 lb per sq in.) is then applied for a specified period, depending on the porosity and/or sapwood content of the timber, and is maintained during the subsequent stage of filling the cylinder with the preservative. When the cylinder is filled, an antiseptic pressure of 5.0 to 12.25 kg per sq cm (75 to 175 lb per sq in.), depending on species, size, etc., is applied until the required absorption is obtained. This is followed by a vacuum as described above. In this case, the preservative expelled on the release of the antiseptic pressure is considerable because of the expansion of the highly compressed air cushion in the cells; a low net absorption, with the cells completely free of any preservative, is obtained. This process is specially recommended for treating imber of mixed species and also timber containing both sapwood and heartwood.

Special treatment for green timber.—The following treatment s are applied specially to green timbers that are generally attacked by wood-destroying agencies during air seasoning.

(1) *Boulton process.*—In this process seasoning and treatment are combined. It consists in boiling green timber under application of a gradual vacuum in the presence of a suitable oil, preferably a preservative like creosote-fuel oil mixture, if ultimately the timber is to be creosoted. This reduces the boiling point of the water contained in the wood, enabling it to evaporate at a temperature below 100° C. In this way a considerable drying of the timber can be effected at lower temperatures with consequently less damage to the wood. Creosoting is completed by employing any of the preservative treatments.

(2) *Steaming-cum-vacuum process.*—This process is essentially meant for seasoning green timber with results that may be better than the pre-seasoning under the Boulton process, and is specially recommended for the treatment of green timber that is very much liable to decay due to fungus during the course of air-seasoning in warm and humid climates. It consists in steaming a timber charge a

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Fig. XVI—4. Normal boucherie treatment of green poles using old type tubes as a reservoir.

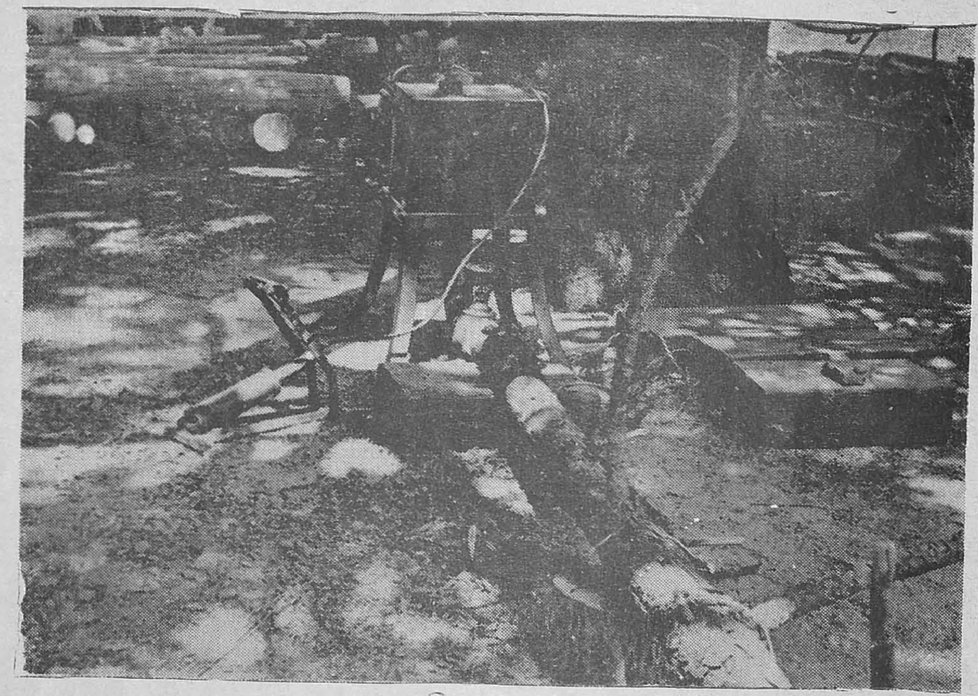

Fig. XVI—5. Boucherie treatment of green poles under low pneumatic pressure. Pressure is created with the help of a foot pump shown attached to the reservoir.

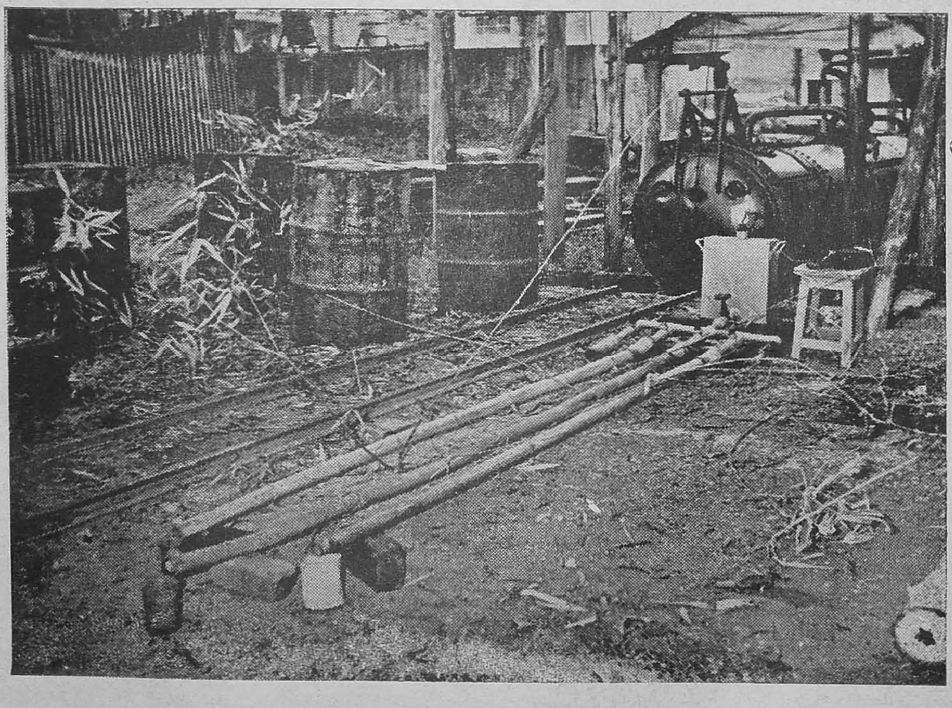

Fig. XVI—6. Boucherie process—bamboo treating apparatus.

about 1.41 kg/sq cm (20 lb/sq in.) gauge pressure for a period which would depend on the size and moisture content of the timber, and then subjecting it to a vacuum. Under these conditions a considerable reduction in the moisture content of the timber is effceted. The charge is then subjected to any of the types of preservative treatment mentioned above.

Choice of treatment

The choice of treatment will be governed by the timber species, its sapwood content and the use to which it is to be put. Treatment is necessary in the case of (1) sapwood of all the species of timber, (2) heartwood of non-durable species, and (3) heartwood of even the durable species if the members are to be placed in the ground and are expected to give long life under severe conditions of deterioration. The recommended practice with regard to choice of preservative, treatment process, absorption and penetration to be adopted is given in Table XVI-1 (pages 262-263).

Incising

The relative ease with which different timbers absorb preservative varies greatly. *Adina cordifolia, Mangifera indica* and *Terminalia myriocarpa* can be completely and easily impregnated under pressure ; while *Anogeissus latifolia, Dalbergia sissoo* and *Lagerstroemia parviflora,* as also fir, spruce and *kail* to a lesser extent, are refractory to treatment. A very drastic treatment using higher temperatures and pressures may be useful. *Incising* is also very useful in the treatment of refractory timbers. It consists in making incisions parallel to the fibres to the depth of penetration required and spaced sufficiently close together so that the lateral spread of the preservative will cover the surface of the timber uniformly and completely. By this means increased absorption and penetration of preservative is invariably obtained.

Classification of Indian timbers with reference to treatability

As a result of extensive research carried out on their treatability, Indian timbers have been classified as follows :

(a) Those timbers that can be treated very easily because the heartwood is very porous and tylosis and pit aspiration are absent. The problem in this case is to get an economically low absorption and, hence, to restrict the absorption of the preservative to below a certain maximum limit consistent with deep penetration. Empty-cell processes are suitable for this class of timbers. Examples of such timbers are *Adina cordifolia, Mangifera indica, Terminalia myriocarpa* and *Tetrameles nudiflora.*

(b) Those timbers of which the heartwood is treatable, but complete penetration of the preservative is not always obtained. The problem in this case is to secure deep penetration consistent with economical absorption. Empty-cell processes are suitable, the pressure and duration of treatment being regulated to suit the characteristics of the wood. Examples of such timbers are *Pinus roxburghii, Acacia nilotica, Terminalia tomentosa* and *Bambusa arundinacea.*

(c) Those timbers of which the heartwood is only partially treatable. Here again empty-cell processes are adopted, regulating the pressure and duration of treatment suitably. Examples of such timbers are *Cedrus deodara, Pinus wallichiana, Cedrela toona* and *Terminalia paniculata.*

(d) Those timbers of which the heartwood is refractory to treatment. These can be impregnated only with considerable difficulty. The problem here is to obtain adequate penetration in the heartwood by incising up to a depth of 2 to 2.5 cm. Full-cell processes are required in such cases. Examples of such timbers are *Picea smithiana, Grewia tiliaefolia* and *Artocarpus chaplasha.*

(e) Those timbers of which the heartwood is very refractory to treatment, the penetration of preservative being practically nil from side or end. These are not amenable to treatment at all. Examples of such timbers are *Lagerstroemia parviflora, Lannea coromandelica, Shorea robusta* and *Dalbergia sissoo.* In such cases diffusion and osmose processes are recommended, as also high pressure treatment after vapour-seasoning and/or oscillating pressure treatment.

(*Contd. on page* 266)

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TABLE

Recommended Practice for

(after Indian Standards

Group	Service conditions of treated timbers	Timbers for which treatment is necessary	Type of treatment
1	2	3	4
1.	Timber in direct contact with ground or water, especially in outside locations, such as poles, piles, pit-props, fence posts, sleepers, bridge timbers, timber for ship-building, etc.	Timbers under Class I containing sapwood and timbers belonging to Classes II and III, if heartwood is treatable	Pressure process, hot and cold process (if applicable), or Boucherie process where practicable
2.	Timbers not in direct contact with ground or water but exposed, such as deck planks, shingles, etc.	Timbers as mentioned under Group 1	Pressure process or hot and cold process (if applicable)
3.	Timbers not in direct contact with the ground or water but exposed and, in addition, given a coat of paint or varnish regularly after preservative treatment, such as exterior doors and windows, etc.	—do—	—do—
4.	Timbers for internal use in dry locations, such as doors, frames and panels, furniture, etc.	—do—	Pressure process or hot and cold process for Class III, soaking for Class II and brushing or spraying for Class I
5.	Shooks for packing cases, ammunition boxes, etc.	Timbers as mentioned under Group 1	Low pressure (1.7—2.8 kg/cm^2), or hot and cold process, or soaking, or brush or spray, depending on the protection required for timbers as mentioned under 4

XVI—1

Preservation of Timber

Institution—IS : 401/1961

Preservatives	Recommended absorption of preservative kg/m^3	Remarks
5	6	7
(a) Creosote or creosote fuel oil mixture (50 : 50)	80-128 for sleepers; 160 for poles, piles and fence posts; and 320 for marine structures	When timbers cannot be treated because of their refractory nature, and facilities for pressure and open tank processes are absent, it is best to adopt the timbers diffusion and osmose processes with green timber
(b) Copper-chrome-arsenic composition	12 for sleepers; 16 for poles, piles and fence posts; and 32 for marine structure	
(c) Acid-cupric-chromate composition	12 for sleepers; 16 for poles, piles and fence posts; and 32 for marine structures	
(a) Creosote or creosote-fuel oil mixture(50:50)	48—80	
(b) Copper-chrome-arsenic composition	8—12	
(c) Acid-cupric-chromate composition	8—12	
(a) Copper-chrome-arsenic composition	6.5	
(b) Acid-cupric-chromate composition	6.5	
(c) Pentachloro-phenol	5.0	
(d) Copper naphthenate	5.0—6.5	
(e) Zinc naphthenate	8.0	
(a) Copper-chrome-arsenic composition	5.0—6.5	
(b) Copper-chrome-boric composition	5.0—6.5	
(c) Copper-chrome-boric composition	8—16	
(d) Chromated zinc chloride 1 : 1	16—32	
(e) Zinc chloride	12—16	
(f) Copper naphthenate	4	
(g) Zinc naphthenate	8	
(h) Pentachloro-phenol	4	
(i) Creosote composition	48—80	
(a) Copper-chrome-arsenic composition 6.0 per cent	5	For shooks of packing cases used for foodstuff only boric acid or borax shall be used.
(b) Acid-cupric-chromate 6.0 per cent	5	
(c) Copper-chrome-boric composition 8.0 per cent	8	
(d) Chromate zinc chloride (1:1) 12.0 per cent	16	

1	2	3	4
6.	Debarked logs and timbers for further conversion (green timbers liable to sapstain attack, especially during humid and hot weather)	—do—	Brush or spray

Penetration of the preservative for :

Group 1—In the case of timbers to be embedded in the ground., like transmission poles, piles, etc., it is desirable to have at least 31 mm ring of sapwood, and care should be taken that the penetration of the preservative is complete in the entire sapwood portion; penetration in the non-durable heartwood, in addition, would ensure a satisfactory service life. In the case of sleepers, while it is best that the penetration is through and through in the sap and non-durable heartwood portions, a minimum penetration of 25 to 40 mm is essential. Where the heartwood of the non-durable timbers is refractory to treatment, incision of all the surfaces, excepting the ends, to a depth of 12 to 19 mm is recommended, particularly in the case of conifers.

5	6	7
(e) Zinc chloride 8.0 per cent	12	
(f) Pentachlorophenol 5.0 per cent	4	
(g) Copper naphthenate 10.0 per cent	4	
(h) Zinc naphthenate 10.0 per cent	8	
(i) Boric acid or borax 2.0 to 2.5 per cent		
(j) Zinc-meta-arsenite (Brush) 8 per cent		
(a) Copper-chrome-arsenic composition 6 per cent		(i) Sodium pentachlorophenate is specially suitable against sapstain.
(b) Acid-cupric-chromate composition 6 pei cent		
(c) Copper-chrome-boric composition 8 per cent		(ii) Timbers treated with (b) and (c) should be kept under cover.
(d) Zinc-chrome-boric acid composition 8 per cent		
(e) Zinc-meta-arsenite 8 per cent		
(f) Sodium pentachlorophenate 1.0 per cent		
(g) Benzene hexachloride (for borers) as water dispersible powder 1.0 per cent		
(h) DDT (for borers only) Dichlorodiphenyl-tri-chlorethene dissolved in kerosene oil 2.0 per cent		

Group 2 to 5—In the case of timbers under Groups 2 to 5, while the sapwood portions should be completely treated for all timbers, a minimum penetration of 19 mm in the case of Groups 2 and 3, 12 mm for Group 4, and 6 mm for Group 5 is essential.

Note.—Percentages in col. 5 refer to strength of solutions to be used for dipping, soaking, brush or spray treatment. For pressure and open-tank treatments, the absorptions are indicated in col. 6 and refer to the non-durable portions of the timber. Unless otherwise stated, the above treatments ensure protection against fungal decay and termite and borer attack. The absorptions given under col. 6 against Group 5 will enable repeated use of the treated material, provided suitably strong timber is originally used.

(*Contd. from page* 261)

A complete classification of common Indian timbers, with respect to natural durability and treatability with preservatives, is furnished in the "Code of practice for Preservation of Timber" (I.S.I. : 1954, IS : 401/1954).

The following Table XVI-2 gives a selective list of timbers recommended for use, after treatment, as substitutes for teak and sal for various purposes, with particulars of their durability and treatability :

TABLE XVI—2

List of common timbers recommended for use after treatment as substitutes for teak and sal for various purposes

Sl. No.	Species	Trade or common name	Durability	Treatability	Uses
1	2	3	4	5	6
1.	*Abies pindrow*	fir	***	d	A_3, B_3, C_3, D_3, E_3
2.	*Acacia nilotica*	babul	***	b	A_1, B_1
3.	*Acrocarpus fraxinifolius*	mundani	***	c	C_2
4.	*Adina cordifolia*	haldu	***	a	B_2 C_2, E_2
5.	*Albizia lebbeck*	kokko	*	c	A_1, B_1, C_1, D_1, E_1
6.	*Albizia odoratissima*	kala siris	*	e	A_1, B_1, C_2, D_2, E_2
7.	*Albizia procera*	white siris	**	c	A_2, B_2, C_2, D_2, E_2
8.	*Anogeissus latifolia*	axle wood	***	e	A_1, B_1, D_1
9.	*Artocarpus chaplasha*	chaplash	**	d	A_2, B_1, C_1, D_2, E_1
10.	*Artocarpus heterophyllus*	kathal	***	—	A_2, B_2
11.	*Artocarpus hirsuta*	aini	***	—	B_1, C_1, E_1
12.	*Bridelia retusa*	kasi	**	e	A_1, B_1, D_2
13.	*Calophyllum* spp.	poon	**	e	A_2, B_2, C_2, E_2
14.	*Cassia fistula*	rajbrik(amaltas)	**	—	A_3, B_3, D_3
15.	*Cedrela toona*	toon	***	c	C_1, E_1
16.	*Cedrus deodara*	deodar	*	c	A_1, B_1, C_1, D_1, E_2
17.	*Chloroxylon swietenia*	satinwood	***	—	A_2, B_2, D_2, E_1
18.	*Chukrasia tobularis*	chickrassy	***	c	A_2, B_1, C_1, D_2, E_1
19.	*Cullenia rosayroana* (*C. excelsa*)	karani	***	b	B_1, C_2
20.	*Cynometra polyandra*	ping	***	b	A_1, B_1, D_1
21.	*Dalbergia latifolia*	rosewood	*	—	E_1
22.	*Dalbergia sissoo*	sissoo	**	e	E_1
23.	*Diospyros* spp.	ebony	***	—	A_2, B_2, D_2
24.	*Dipterocarpus* spp.	gurjan	***	b	A_1, B_1, C_2, D_2
25.	*Dipterocarpus indicus*	gurjan	**	b	A_1, B_1, C_2, D_2
26.	*Dipterocarpus macrocarpus*	hollong	***	a	A_1, B_1, C_2, D_1
27.	*Dysoxylum malabaricum*	white cedar	*	—	C_1, E_1

1	2	3	4	5	6
28.	*Fagara budrunga*	mullilam	**	—	B_1, C_1, E_1
29.	*Gmelina arborea*	gamari	*	—	C_1, E_1
30.	*Grewia* spp.	dhaman	**	d	A_1, B_1, D_1
31.	*Grewia tiliaefolia*	dhaman	**	d	A_1, B_1, D_1
32.	*Hardwickia binata*	anjan	*	e	A_1, B_1, D_2
33.	*Holoptelea integrifolia*	kanju	***	b	E_2
34.	*Hopea parviflora*	hopea	*	e	A_1, B_1, D_1
35.	*Hymenodictyon excelsum*	kuthan	***	e	C_2, E_3,
36.	*Juglans regia*	walnut	***	—	E_1
37.	*Kingiodendron pinnatum*	piney	*	e	B_2
38.	*Lagerstroemia hypoleuca*	pyinma	**	—	A_1, B_1, C_2, D_1
39.	*Lagerstroemia lanceolata*	benteak	*	e	A_1, B_1, C_2, D_1, E_2
40.	*Lagerstroemia parviflora*	lendi	***	e	A_1, B_1, D_2
41.	*Lagerstroemia speciosa*	jarul	**	e	A_1, B_1, D_2
42.	*Madhuca indica*	mahua	*	e	A_2, B_2, D_2
43.	*Mangifera indica*	mango	***	a	A_2, B_2, C_2, E_2
44.	*Mesua ferrea*	mesua	*	e	A_1, B_1, D_1
45.	*Michelia* spp.	champ	***	—	A_2, B_1, C_1, D_2, E_1
46.	*Mimusops* spp.	bullet wood	*	—	A_1, B_1, D_1
47.	*Mitragyna parvifolia*	kaim	***	b	B_2, C_2, E_2
48.	*Ougeinia oojeinensis*	sandan	*	—	A_1, B_1, D_1
49.	*Palaquium ellipticum*	pali	**	e	B_1, C_1
50.	*Phoebe* spp.	bonsum	***	c	A_2, B_2, C_1, D_2, E_1
51.	*Picea smithiana*	spruce	***	d	A_3, B_3, C_3, D_3, E_3
52.	*Pinus roxburghii*	chir	***	b	A_2, B_2, C_2, D_3, E_2
53.	*Pinus wallichiana*	kail	***	c	A_3, B_2, C_2, D_3, E_3
54.	*Poeciloneuron indicum*	ballagi	**	e	A_1
55.	*Pterocarpus dalbergioides*	padauk	*	c	A_1, B_1, C_1, D_1, E_1
56.	*Pterocarpus marsupium*	bijasal	*	e	A_1, B_1, E_1
57.	*Schima wallichii*	chilauni	***	d	A_3, B_3, C_3, D_3
58.	*Schleichera oleosa*	kusum	***	a	A_1
59.	*Shorea assamica*	makai	***	c	A_2, B_2, C_2
60.	*Syzygium cumini*	jaman	**	e	A_1
61.	*Tamarindus indica*	imli	***	—	A_1
62.	*Terminalia arjuna*	arjun	**	b	A_1, B_1, D_2
63.	*Terminalia bellerica*	bahera	***	b	A_2, B_1, D_1
64.	*Terminalia bialata*	white chuglam	***	e	A_2, B_2, C_1, D_2, E_1
65.	*Terminalia manii*	black chuglam	***	a	A_2, B_2, C_1, D_2, E_1

1	2	3	4	5	6
66.	*Terminalia myriocarpa*	hollock	***	a	A_2, B_2, C_1, D_2, E_2
67.	*Terminalia paniculata*	kindal	**	c	A_2, B_2, D_2
68.	*Terminalia procera*	white bombwe	***	b	A_2, B_2, C_2, E_2
69.	*Terminalia tomentosa*	laurel	**	b	A_1, B_1, D_1
70.	*Xylia xylocarpa*	irul	*	e	A_1, D_1

LEGEND

Durability

*Heartwood highly durable and requires no preservative treatment.

**Heartwood moderately durable and requires mild preservative treatment.

***Heartwood non-durable and requires thorough preservative treatment.

Treatability

(a) Heartwod easily treatable.
(b) Heartwood treatable, but complete penetration not always obtained.
(c) Heartwood only partially treatable.
(d) Heartwood refractory to treatment.
(e) Heartwood very refractory to treatment, penetration of preservative being practically nil even from ends.

Uses

A_1— 1st choice for beams, rafters, purlins and trusses.
A_2— 2nd —do
A_3— 3rd —do—
B_1— 1st choice for *chowkhats* (frame work).
B_2— 2nd —do—
B_3— 3rd —do—
C_1— 1st choice for door and window leaves and ceilings.
C_2— 2nd —do—
C_3— 3rd —do—
D_1— 1st choice for struts and columns.
D_2— 2nd —do—
D_3— 3rd —do—
E_1— 1st choice for furniture.
E_2— 2nd —do—
E_3— 3rd —do—

Fire Protection of Timber

Apart from deterioration from biological causes as mentioned earlier, timber is also susceptible to serious damage from fire. This is because it consists mainly of cellulose which is combustible. Tests on the natural resistivity of timber with reference to fire indicates that, while primarily all timbers do catch fire when exposed to high temperatures, the amount of deterioration in individual species varies to some extent, depending on the interrelated properties like structure, density and porosity, and also on the infiltrated chemical substances. It is no doubt true that wood should be dry before it catches fire ; decayed wood can be ignited more easily than sound wood. At about 200° C, considerable time is required to kindle even dry timber. At 275°C, timber slowly gets charred and then finally ignites. At 400°C, the ignition takes place quite quickly. Generally, a temperature of over 1,000°C is reached in fires. At this temperature, the small variations in the natural resistance of timbers matter little, and all structural timbers behave almost in the same way. Under these circumstances, it is the type of construction and the cross-section of the timber members of a structure that are the controlling factors, and not the species of timber used. Heavy timber constructions, known as "mill

construction", is regarded as a safe type for a building against fire. As regards size of the timber members, any cross-section over 15 cm×15 cm is said to withstand fire better than steel. Iron and steel get easily and quickly twisted and crushed under load when exposed to high temperatures. On the other hand, wooden beams and columns, when used in large cross-sections soon develop a charred shell which retards combustion and thus enables the timber to retain its strength for a fairly long period. In fact, in the initial stages of fire, timber actually increases in strength in a small measure because its moisture content is reduced due to heat, and any loss in strength suffered by timber due to carbonization more than compensated for by this increase in strength due to loss of moisture. This is not so with iron which continuously loses strength as the temperature and period of exposure to fire are increased. Iron has a very high coefficient of thermal expansion. Therefore, an iron girder quickly throws off the walls on which it rests when a building is on fire. This leaves very little time for the occupants of a house to rush out and save themselves. In its low coefficient of thermal expansion, particularly along the grain, a wooden beam rarely causes collapse of the walls in a burning building on fire. In all fires, occurring in residental houses and factories, it is not the loss of property that is so important as that of human life. In this sense a timber building decidedly offers greater protection than a metal structure because it gives ample time to remove occupants and property. This is particularly so when the building is several storeys high. It is therefore advisable that timber is used in place of iron in all structures like residential buildings, factories, bridges, ships, aeroplanes, etc. The natural resistance of these timber structures against fire can considerably be increased by adopting suitable chemical treatment.

The chemicals that are generally used in the protection of timbers against fire can be grouped under three categories : (1) those that are highly hygroscopic like zinc chloride, sodium chloride, etc., which retard fire because they give off water vapour when exposed to fire and thus act as automatic extinguishers of fire; (2) those that give off (due to decomposition when exposed to fire) gases like carbon dioxide, ammonia, nitrogen, etc., which do not support fire, e.g., ammonium sulphate and nitrate, calcium carbonate, sodium bicarbonate, etc; and (3) those that crystallize in the wood, and in some cases swell up in wood on exposure to fire, plugging the pores in the timber and thus keeping out, to that extent, air containing oxygen which supports the fire, e.g., sodium tetraborate, boric acid, borax, magnesium phosphate, ammonium phosphate (monobasic).

Some of the fire-proofing compositions may be mentioned :

(1) For impregnation :

(i) Inside use : (a) Zinc chloride, (b) Ammonium phosphate (monobasic), and (c) Ammonium borate.

(ii) Outside use : (a) Zinc chloride 54 parts and ammonium phosphate (monobasic) 46 parts, (b) Chromated zinc chloride, (c) Magnesium arsenate, (d) Magnesium pyrophosphate, (e) the fire-resistant-cum-antiseptic composition recently evolved at the Forest Research Institute, Dehra Dun, which consists of :

Boric acid	3 parts by weight
Copper sulphate	1 part by weight
Zinc chloride	5 —do—
Sodium dichromate	6-7 —do—
Water	100 —do—

[The above composition in 16 per cent water solution should be impregnated in timber to aim at an absorption of 48-128 kg per cu m (3-8 lb per cu ft) of dry salts].

(2) Fire-retardant paints :

(a) Barytes	1.2 parts by weight	medium		Sodium silicate 0.75 part and soft soap 0.36 part
Asbestos	0.6 —do—			
Borax	0.12 —do—			
Ammonium phosphate	0.06 —do—			
Medium	2.4 —do—			

(b) Water glass	27 parts	by weight
Talcum powder	48	—do—
Water	25	—do—
(c) White lead	41	—do—
Borax	32	—do—
Raw linseed oil	27.8	—do—
Turpentine	3.6	—do—
Japan drier	0.6	—do—
(d) Ammonium sulphate	28	—do—
Ammonium carbonate	14	—do—
Borax	7	—do—
Boric acid	7	—do—
Alum	14	—do—
Water	500	—do—

(3) Fire-resistive paint (developed at the Forest Research Institute, Dehra Dun) :

Ashes (Boiler)	35 parts	by weight
Mica powder	30	—do—
Borax	15	—do—
Asbestos powder	10	—do—
Zinc oxide	10	—do—

The ingredients of the paint are individually ground to a fine powder and then mixed in proportion mentioned above. To this is added glue of the following composition :

Aerolite FFD (imported)	450 parts	by weight
Water	180	—do—
Hardner CHW	54	—do—

This glue is added slowly to the above powder in the ratio of 4 parts of powder to 1 part of glue (i.e., at the rate of 20 per cent) along with 5 parts of water for making it of suitable consistency for application by means of brush in about 1.3 cm thick layer. (It was, however, found that if locally manufactured Cascamite 6D glue is used, its quantity should be increased to 35 per cent—3 parts of water being further added).

General specifications for a commercial wood preservation plant

A typical commercial plant consists essentially of :

(1) An air-seasoning yard where the timber is properly piled to air-dry. Wood is not, in general, ready for treatment till the moisture content is below 25%, or even less.

(2) A mild steel cylinder of a suitable size, say 15 m long and 2.4 m diameter (fitted with a suitable door), which can take the timber for impregnation. It should be fitted with steam coils at the bottom and suitable inlet and outlet pipes.

(3) The machines required for drawing a vacuum and for creating pressure. The former should be capable of drawing air to a pressure of 37.5 to 60 cm (15 to 24 inches) of mercury ; the latter must be able to work up pressures up to 14.06 kg per sq cm (200 lb/sq in).

(4) Trolleys, cranes, and a railway line for transporting the material.

(5) A boiler complete with accessories for the supply of steam to work the machines and to head the antiseptic if hot treatment is required. It should be capable of giving steam at 10.5 kg per sq cm (150 lb/sq in.) pressure.

(6) Storage and working tanks of suitable capacities to hold the antiseptic.

(7) Recording thermometer and gauges for vacuum and pressure.

Other Methods of Treatment

Ground-line treatment in situ

Occasion frequently arise, when it is not possible to treat fence posts, telegraph poles, etc., before installation. These can be treated, to some extent, by the application of preservative at least to the ground-line section. In Germany, the impregnation of fence poles and telegraph poles *in situ* by the diffusion method has been tried with some success. The preservative in a paste form is injected into the wood at several points around the ground-line section, and it spreads by diffusion. Satisfactory penetration is obtained when the timber is green. Through such a treatment does not give complete protection to the entire but section of standing potes, yet it is of some value in retarding decay and termite attack at the ground-line, where decay first appears and progresses most rapidly and strength reductions caused by loss in diameter due to decay and termite attack are most serious.

Ground line treatments are suitable for treatment of poles which could not be treated prior to installation. All these methods aim at surrounding a section of the pole, from a few centimeters above the ground line to 30 or 45 cm below, with preservative, part of which is eventually absorbed by the sapwood of the pole. In addition to several treatment referred to already, the following deserve mention.

Charring and spraying treatment.—This is a well known method for protecting timber in contact with the ground. It is applicable to individual pieces as also to poles *in situ*. The wood is charred and then sprayed with preservative. Charring destroys the stored food supplies [in the parenchymatous tissue of the outer layers of wood, and thus renders the charred timber useless as food material for insects and fungi. Charring, alone or in combination with spraying, is usually practised only in the case of poles for temporary fencing, when the cost of preservative treatment is considered too high for the purpose.

Puddling treatment.—This is an *in situ* treatment. The soil surrounding the timber (poles, posts, etc.) is loosened to a depth of 30 cm all round and is saturated with preservative. The preservatives, used in these ground-line treatments are usually creosote and oily solutions of copper napthenate. A combined creosote and salt treatment also bids fair to be successful. They aim at sterilizing the ground in immediate contact with the ground and preventing infestation of fungi and insects for some time.

Durability of treated and untreated timbers

The question of the relative durability of treated and untreated timbers of various species, under varying conditions of service and treated by various methods with different preservatives, deserves careful study. Fairly complete records are available regarding the life of treated and untreated timbers in graveyard tests at the Forest Research Institute, Dehra Dun. In the Table XVI-3, the service life of treated timber is compared with that of untreated timber. The inference is obvious that treatment substantially increases service life.

Table XVI—3

Comparative service life of treated and untreated timbers in graveyard tests

Sl. No.	Preservative	Species	Process	Service life obtained: Treated Yrs.	Treated mths.	Untreated Yrs.	Untreated mths.
1.	Creosote	Chir	Open tank	34	2	2	10
2.	”	Kail	” ”	24	1	9	11
3.	”	Semal	” ”	34	2	0	9
4.	”	Sal	” ”	14	11	11	0
5.	Ascu 8%	Chir	Pressure	16	7	0	11
6.	”	Kail	” ”	16	7	8	4
7.	”	Deodar	” ”	16	7	13	11
8.	Creosote & fuel oil mixture	Chir	Lowry process	17	0	0	11
9.	”	Kail	” ”	17	0	8	4
10.	”	Deodar	” ”	17	0	13	11

Source : Wood Preservation in India ; *Indian Forest Bulletin.* No. 168 (N. S.), Wood Preservation, 1953.

Economics of treatment

In any scientific analysis of the cost of treated timber as compared with that of untreated timber, the best course to adopt is to use the cost of timber in place, including the cost of erection, and calculate the annual charge. The annual charge is defined as "cost per year of the annual payment, required to extinguish an interest-bearing debt during a period of years, corresponding to the life of the material in service". It is calculated by using the formula :

$$A = P\left\{r + \frac{r}{(1+r)^n-1}\right\}$$

$$= P\frac{r(1+r)^n}{(1+r)^n-1}$$

where A is the annual charge,
P is the cost of material plus erection,
r is the rate of interest, expressed in decimals, e.g., 5%=0.05, and
n is the expected service life.

Suppose a small cottage is to be built with a roof consisting of treated or untreated thatch and it is desired to ascertain which is more economical. The comparative charges may be calculated as under :

	Untreated Rs.	Treated Rs.
Cost of thatching grass for 10 sq m of roofing, with 15 cm thick layer of grass	15	15
Cost of chemical treatment	—	20
Cost of erection of roof	10	10
Total cost in place	25	45
Service life	3 years	25 years
Interest (interest 3% + maintenance charge 2%)	5%	5%
Annual charge $A=P\frac{r(1+r)^n}{(1+r)^n-1}$	9.18	3.19
where P =	25	45
r =	0.05	0.05
n =	3	25

$$\text{Annual charge, untreated} = 25\left\{0.05 + \frac{0.05}{(1.05)^3-1}\right\} = 9.18$$

$$\text{Annual charge, treated} = 45\left\{0.05 + \frac{0.05}{(1.05)^{25}-1}\right\} = 3.19$$

Hence an investment of Rs. 20 in treating grass saves Rs. (9.18—3.19) × 25 or about Rs. 150 in 25 years. To put in a different way, it is seen that, in spite of an increase of Rs. 20.00, or 80%, on the initial cost of roofing due to treatment, the net saving as a result of treatment will be Rs. 5.99, or 65%, per year for a period of 25 years.

In the following table the cost and service life of treated and untreated chir-pine timber are compared. It will be seen that the annual cost of treated wood is much less than that of untreated wood.

TABLE XVI—4

Statement showing cost and annual charges of treated and untreated chir-pine wood for specific uses

Category of use	Untreated timber			Treated timber		
	Cost per tonne (Rs.)	Service life (years)	Annual charges per tonne(Rs.)	Cost per tonne (Rs.)	Service life (years)	Annual charges per tonne (Rs.)
1. Transmission poles	500	3	184	600	20	48
2. Railway sleepers	500	5	115	575	20	46
3. Building timber	500	7	86	575	60	30

Treated timber, used in a similar manner to untreated wood, will usually be found to be much more economical under conditions conducive to biological deterioration. Another advantage in the use of treated wood is that species of low natural durability which are available at a lower cost can be utilised as successfully as naturally durable species which are available at a much higher cost. The appreciable salvage obtained from dismantling wooden buildings is an added advantage of wood over other building materials. Increased use of sapwood, permissible as a result of preservative treatment, is decidedly economical, compared with the higher cost of timber free from sapwood. Also , wood preservation permits the utilisation of numerous non-durable secondary species that would otherwise be left valueless in the forest during logging; thus the exploitation of the forest as a whole is rendered less costly. Further, the availability of usable secondary species in adequate quantities keeps the price of primary timbers at a steady level.

REFERENCES

Anon 1951 Canadian Woods, their Properties and Uses ; Edmond Cloutier, Kings' Printer and Controller of Stationery, Ottawa.

Bryan, J. 1946 Methods of applying wood preservatives, Part I—Non-Pressure methods; *Forest Product Research Record* No. 9 (Wood Preservation Series No. 2) ; His Majestry's Stationey, London.

Blake, E. G. 1924 The Seasoning and Prservation of Timber ; Chapman and Hall, London.

Desch, H. E. 1956 Timber, its Structure and Properties; Macmillan, London.

Findlay, W. P. K. 1962 Preservation of Timber ; Adam and Charles Black, London.

Hunt, G. M. & Garratt, G.A. 1953 Wood Preservation ; McGraw-Hill Book Company, New York.

I. S. I. 1962 Code of practice for preservation of timber (Revised), IS : 401-1961 ; Indian Standards Institution, Delhi.

Kamesam, S. 1936 Note on protecting Indian Sturctural timbers against fire, termites and fungi *Indian For. Rec.* (N.S.), 1 (4) Utilization ; Manager of Publication, Delhi.

Kamesam, S. 1936 Treated timber for earthquake resistant structures; *Timber Development Series* No. 6 ; F. R. I., Dehra Dun.

Maclean, J. D. 1952 Preservative Treatment of Wood by Pressure Methods, Agriculture Handbook No. 40 ; U.S. Govt. Printing Office, Washington.

Moore, G. E. 1945 Improved Wood ; Forest Products Laboratories, Dominion Forest Service, Ottawa.

Narayanamurti, D. 1942 Short note on wood preservation for users in India; *Indian For. Bull.* No. 110, Utilization ; Manager of Publications, Delhi.

Narayanamurti, D., Purushotham, A. & Pande, J. N. 1947 Preservative treatment of bamboos ; *Indian For. Bull.* (N.S.), No. 137, Composite Wood & Wood Preservation ; Manager of Publications, Delhi.

Purushotham, A., Pande, J. N. & Jadhav, Y.G. 1953 Wood Preservation in India; *Indian For. Bull.* (N.S.), No. 168, Wood Preservation Manager of Publications Delhi.

Purushotham, A., Sudan, S. K. & Vidya Sagar 1954 Preservative treatment of green bomboos under low pneumatic pressures *Indian For. Bull.* (N.S.), No. 178, Wood Preservation ; Manager of Publications, Delhi.

Richardson, N.A. 1937 Wood preservatives; *Forest Product Research Record* No. 17 (Wood Preservation Series No. 3) ; His Majesty's Stationery Office, London.

CHAPTER XVII

MODERN TIMBER-ENGINEERING TECHNIQUES

Introductory

Timber is generally used for doors and windows, roof trusses of small and large spans, purlins and rafters, and roof joists and beams of almost every buildings that is erected in the country, but "all-timber" structures are not common in India except in hilly regions, e.g., Jammu and Kashmir, Himachal Pradesh, Assam, Andamans. Even for the limited structural uses to which timber is put, engineers and builders are facing considerable shortage of timber. The following are among the reasons for this shortage :

(i) Many timber-using industries have come into being in recent times, and their demand for timber is as heavy and as important as the requirements of the building trade.

(ii) So far engineers have relied on a few timber species of outstanding qualities and, even in their case, have followed very strict specifications about the permissible natural defects. This circumstance has accounted for a colossal waste of a few selected timbers and a complete neglect of the many secondary ones.

(iii) Resources of timber have not only increased with the increasing demand but have either gradually diminished or, at the most, remained stationary.

uch a shortage of timber has occurred in other parts of the world also, but the more advanced countries have met this challenge through improved timber-engineering techniques.

Modern timber-engineering was born in Germany some 60 years ago. In the wake of the two World Wars, resulting in an acute shortage of steel, it got further impetus throughout Europe, the United Kingdom and the U.S.A., and created a worthy place for timber in modern structures. The aim in modern timber-engineering is to incorporate in timber structures the developments already made in steel and R.C.C. structures. A remarkable aspect of this development in India is the use of small sized sections and short lengths of timber in construction. Also of importance is the fact that, with the techniques of wood seasoning and peservative treatments that have been evolved, a vast variety of species of woods can be used in our country and not merely the few conventional timbers hitherto used.

Modern systems of timber-engineering

Various systems of timber construction have been developed in India during the last 15 years for building both light and heavy timber structures, such as residential buildings, schools, gymnasium halls auditoriums, sports pavilions, warehouses, theatres, exhibition halls, factory structures, aeroplane hangers, radio towers, electric and telegraphic transmission posts, grain silos, etc. These systems can be divided into four major categories, according to the manner in which the jointing of structural members is made, as follows :

(i) Latticed type nail-jointed timber construction.

(ii) Timber construction with hardwood disc-dowel connectors or improvised metal connectors as timber-jointing devices.

(iii) Lminated timber construction.

(iv) Lamella timber construction.

A brief description of each type is given below :

(i) *Latticed type nail-jointed timber construction* (Fig. XVII-1)

Nail-jointed timber structures are by far the easiest, cheapest and quickest to build when small spans (upto 12 m) are required to bear the normal loading on roofs. Ordinary carpentary tools and machines will serve the purpose, and fabrication and erection methods are not complicated. Engineers,

architects and builders can make the best use of secondary species in small sizes as structural material, employing nails as jointing devices, for construction of storehouses, factory blocks, residential buildings etc. This system is apparently the one best suited for Indian conditions of climate, labour and equipment, especially for rural construction, agricultural projects, forest buildings, etc., and has engaged the particular attention of the Forest Research Institute (F.R.I.), Dehra Dun, for research data, design developments and fabrication techniques.

(ii) *Timber construction with hardwood disc-dowel connectors or improvised metal connectors as timber jointing devices*

As timber joints are the weakest parts of any wooden structure, it is usually the practice to use heavy steel guesset plates and bolts to transmit the loads from one member to the other. As timber always fails by shearing or crushing of fibres at places where bolts are fitted in orthodox bolted-joint structures, the function of hardwood disc-dowels (which are incorporated in the joints) is to distribute the shearing stresses on a larger area of wood. Taking the strength efficiency of a jointless structure as 100 per cent, the strength efficiency of a dowel-jointed constructions 60-70 per cent and that of a nail-jointed construction 50-60 per cent. In using the disc-dowel, economy is effected in large span strutured by saving in the use of steel. Research work on timber and improvised metal connectors is being carried out at F.R.I., Dehra Dun, and a number of large-span timber structures, including heavy bridges, have been erected.

A number of hardwoods have been tested at the F.R.I., Dehra Dun, for use as disc-dowels and the nine species found to be suitable are, babul (*Acacia arabica*), axlewood (*Anogeissus latifolia*), rosewood (*Dalbergia latifolia*), sissoo (*D. sissoo*), dhaman (*Grewia tiliaefolia*), sandan (*Ougeiniai oojeinensis*), padauk (*Pterocarpus dalbergioides*), sal (*Shorea robusta*) and 'irul (*Xylia xylocarpa*) dowel-jointed timber roof truss can be manufactured at about a quarter of the cost of a steel truss. One such structure of 21.3 m (70 ft.) span using sal wood (*Shorea robusta*) in three hinged arch type trusses has been designed and erected in 1958 by the Timber Engineering Branch F.R.I., Dehra Dun. (See Fig. XVII-2).

(iii) *Laminated timber construction*

(a) *Glued laminated timber construction.*—This was developed more recently in Europe and the U.S.A., but has gained wide-spread appreciation for appearance and performance. It meets admirably the requirements of modern design and architecture. Between 1940 and 1954, laminated glued-timber structures, including heavy bridges became a fashion with architects and engineers in Europe and the U.S.A., wherever large-span timber structures, stream-lined and robust in appearance, had to be constructed. This type of construction has been made possible by the recent development of waterproof synthetic glues of exceedingly high strength. Engineers are now moulding short lengths and small sections of wood to big sizes and desired shapes to span widths upto 120m. This enables more complete utilization of small sized timber of low grades and inferior species, and thus helps conservation of supplies of clear material and of the rare and more valuable woods. It also results in 100 per cent jointing efficiency compared to an efficiency of 60-70 per cent in disc-dowel joints, 45-50 per cent in nailed joints and 25-30 per cent in ordinary carpentary joint structures. Where beauty in modern architectural get-up is the object, such as in theatres, assembly halls, stadia, etc., these structures stand comparison with concrete and steel work. As it is usually a workshop product and not assembled at site, the difficulties on account of transport and availability of skilled labour and erection gadgets for installation of heavy members, etc. will perforce restrict their use to urban areas.

e strength of glued laminated structures lies in skilful workmanship, proper uniform seasoning of the timber used, and the use of glues of reliable quality. Any shortcoming in these requirements causes structural failures. In India, glues required for this purpose will have to be imported, and this will make these structures too costly. Before they are undertaken, preliminary trials should be made with small-sized structures using Indian softwoods and hardwoods and imported synthetic glues. If the results are satisfactory full-sized structures should be installed and their behaviour under actual service conditions in this country studied. If they come up to standards, indigenous glues will have to be developed to make their construction on a large scale economic. They cannot, however, compete with nailed and dowelled construction in respect of costs.

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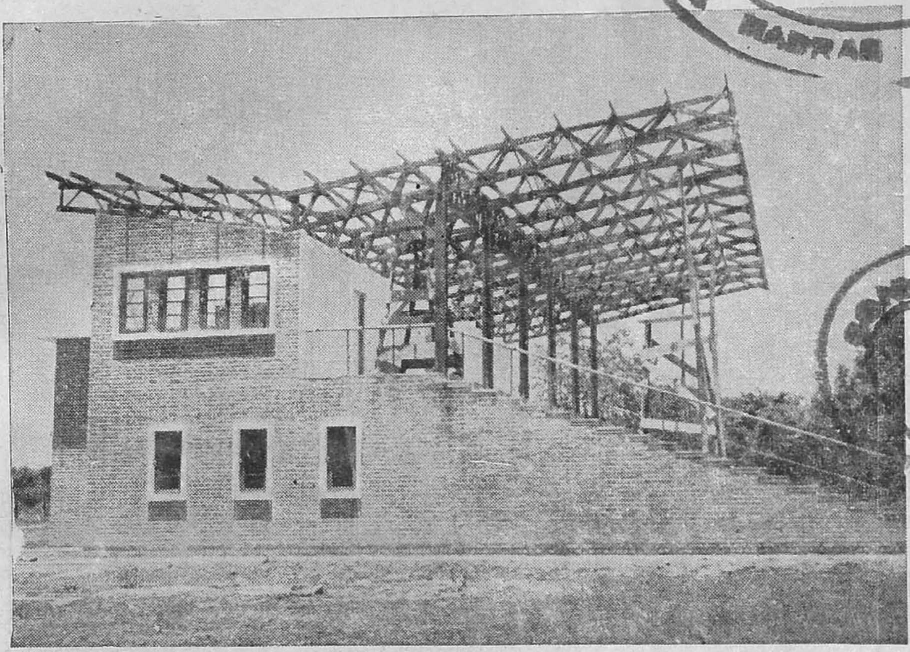

Fig. XVII—1. Latticed type nail-jointed timber construction.

(A 8.5 metres span nail-jointed cantilever timber trussed sports pavilion at Dehra Dun).

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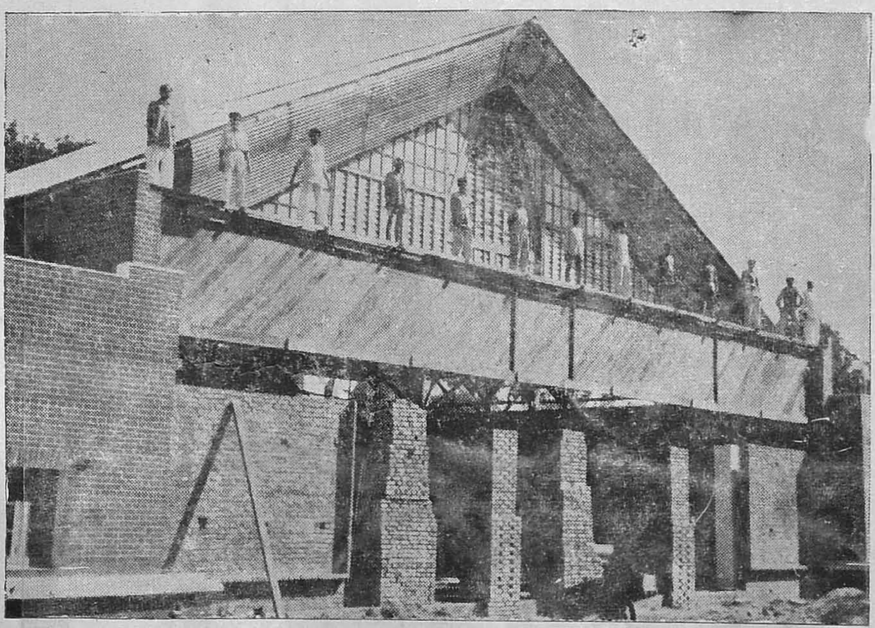

Fig. XVII—2. Solid web type timber girders.

(A. 21-3 metres span nail-jointed girder being hoisted in parts).

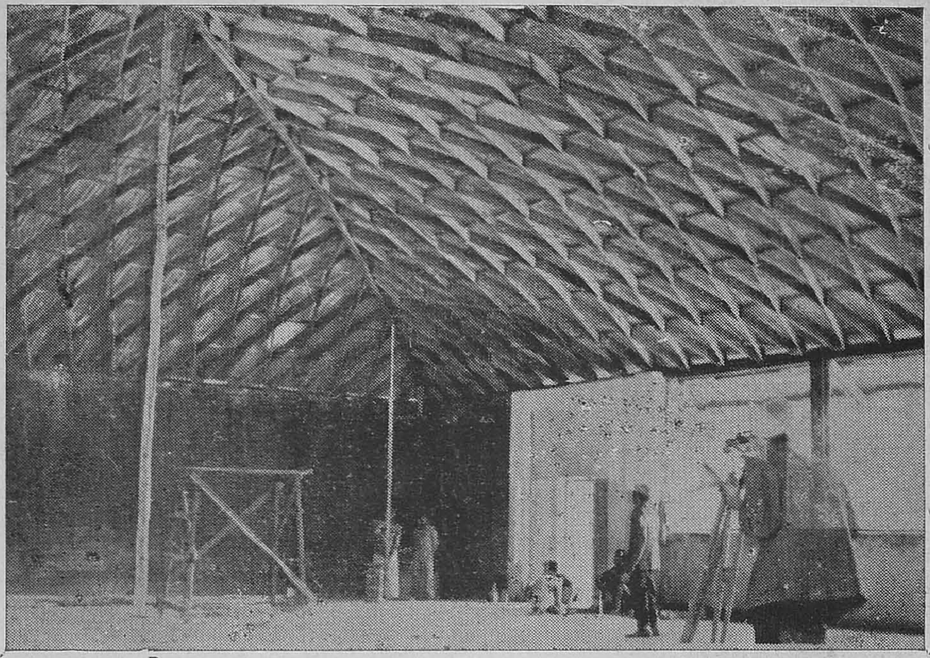

Fig. XVII—3. Lamella arch roof in timber.

(An inside view of a 18.:3 metres span timber lamella arch roofed auditorium at Dehra Dun).

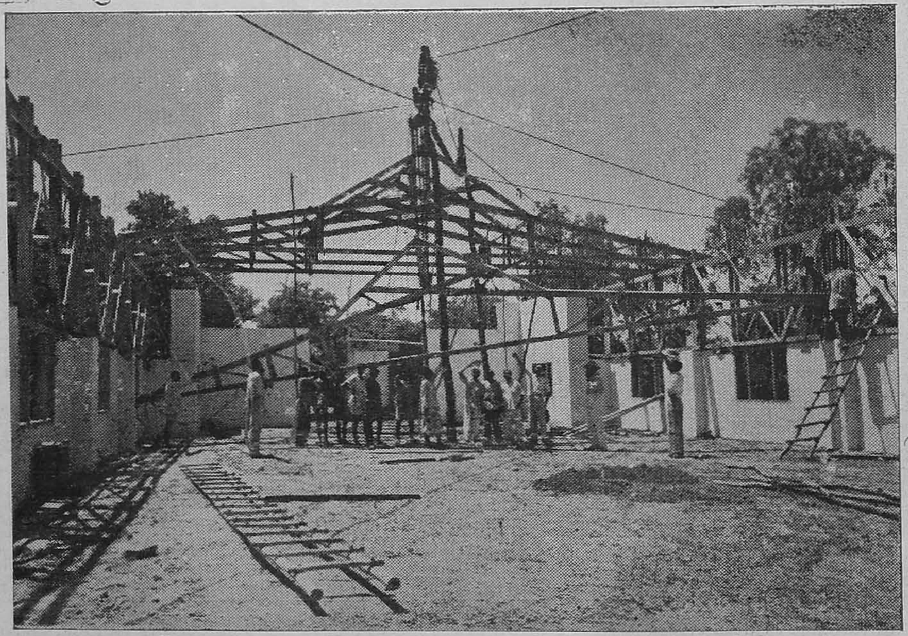

Fig. XVII—4. Nail-jointed timber roof.

(A 13:7 metres span nail-jointed timber roof trussed exhibition hall at Dehra Dun. Roof trusses resting on parallel sided nail-jointed trusses are being hoisted).

(b) *Mechanically laminated construction*—In order to meet the persistent demand for laminated construction in cases of large span beams and joists etc., for public galleries, bridge girders etc., a new type of construction, i.e., mechanically laminated construction with nails acting as mechanical fasteners, has been developed at the Timber Engineering Branch, F. R. I., Dehra Dun, and various structures for observation and demonstration have been erected to catch up with the particular demand of heavy loaded engineering units through use of short length small dimensioned timber of secondary species of timber.

(iv) *Lamella timber construction* (Fig. XVII-3)

Lamella timber-roof construction was first developed in Germany as long ago as 1908. Considerable work of investigation has been carried out at the F.R.I., Dehra Dun, and a number of observation and demonstration structures have been erected. The lamella roof is made up of relatively short timber boards of uniform length and cross-section, their dimensions depending on the span of the arch and the loads on the roof. The lamellae are bevelled and bored at the ends and bolted together at an angle so as to form a network of thin, uniform-sized, short-length timber-board structure, in the shape of an arch of mutually braced and stiffened timbers, to cover wide spans without intermediate supports. The structural elements of the lamella roof are decorative in themselves and this fact will be especially valuable in the design of churches, auditoriums, restaurants, aeroplane hangars, workshops, etc. It has an added advantage in that it resists fire because of the special design of the lamella roof. A big hole may be burnt through the network, sheathing and roofing at any place in the roof without the roof structure collapsing, since the loads are then redistributed to the less damaged timbers around the opening. The wooden members will have to burn or char almost completely before they collapse. Panels formed by the lamellae provide effective fire-stops, preventing rapid spread of fire, and thus a fire can easily be extinguished before serious damage has resulted. The structure is also acoustically perfect as the deep lamella pattern becomes a natural break for sound. With these advantages and its economy in labour and material, lamella construction promises a great variety of uses in India.

Investigations at the Forest Research Institute, Dehra Dun

For over thirty years, the F.R.I., Dehra Dun, has done pioneering work on the utilization of timber and since the starting of the Timber Engineering Branch in 1953, much work has been done by way of research, design and demonstration, on modern timber-engineering techniques. The methods of construction developed at the Institute do not require, as in the conventional type of wood construction still largely in vogue in this country, timber of long lengths and large dimensions with joints strengthened by mild-steel bolts and straps (or fish-plates). Small dimensioned short lengths of timber in the form of offcuts, side slabs and rejections, associated with the conversion of logs into standard sizes such as railway sleepers, can be used for the purpose, the jointing being done by wire nails. Important aspects of the techniques involved are discussed below.

Choice of wood

Conventional timber engineering has centred largely round a few timber species, such as teak (*Tectona grandis*), sal (*Shorea robusta*), deodar (*Cedrus deodara*), etc., of great natural durability coupled with desirable structural qualities. With the development of methods to impart durability to non-durable timbers by impregnation with preservatives and to achieve dimensional stability in woods through proper seasoning, a very large number of wood can be used for constructional purposes, the choice being conditioned only by the strength properties required of the wood for the given purpose and design. In the order of importance the following mechanical properties are often required of woods used for structural purposes : (1) compression parallel to grain, (2) modulus of elasticity, (3) extreme fibre stress in bending and tensio parallel to grain, (4) compression perpendicular and parallel to grain, and (5) shear horizontal. These mechanical properties are the basis from which safe working stresses

of timbers, which facilitate the designing of timber structures, are derived. Safe working stresses have been evaluated and published for a large number of commercially important species of Indian woods (Limaye ; 1946).

With choice thus extended to a large number of available species of wood, the selection for any given purpose should be of the most economical species among them. For this purpose it is necessary to classify structural timbers suitably with reference to their strength properties, their natural durability, the spans they are suited for, and whether the structures are to be of permanent or temporary nature. Such a classification, called "Rational Grouping of Structural Timbers", as worked out for 87 timber species (Masani : 1966) is given in Table XXII-2 at the end of Chapter XXII ("Structural Uses of Timber"). The 87 species have been grouped under three major heads, viz., "super", "standard" and "ordinary", to indicate the relative spans of structure, viz., large, medium and small, for which their strength (modulus of elasticity and extreme fibre stress in bending and tension along the grain) fits them. Those species of wood which combine strength with high natural durability or easy treatability are indicated for permanent structures and those non-durable woods which are strong but can only be treated with difficulty in small sizes and under pressure treatment are indicated for temporary structures. Species which are not even half as strong as teak and those which are non-treatable and non-durable have been excluded from the classification, as they are not recommended for structural purposes. With such a classification, of a number of species suitable for a particular type of structure, the one locally available at a low cost can be easily selected.

Types of joints and fasteners used in modern timber-engineering techniques

In any framed structure, the joints are considered to be the weakest points. In the conservative type of wood-framed construction, steel fish-plates, straps, etc. are used to strengthen these weak points. Large quantities of steel in the form of fish-plates or straps and bolts and nuts add considerably to the cost of such structures. Further, the stresses of timber at joints used in conjunction with mild-steel bolts generally require the use of large dimensions of timber, usually in excess of sections required to transmit the actual stresses, thus contributing to a lavish use of timber.

The following types of fasteners and joints, characteristic of modern timber-engineering techniques, eliminate entirely the use of steel plates and straps and conduce either to reduce the severity of stresses or to distribute the stresses at joints on a larger area, thus ensuring safety and economy in construction.

(a) *Nails.*—Nails are valuable fasteners and are in everyday use with almost all the manufacturers of wood products in Europe and the U.S.A. Structural engineers have also taken to nailing as an effective, traditionally simple, jointing device for the timber trusses of moderate spans, especially for trussed rafters. By preboring the holes, if necessary, in the case of hardwoods, it is possible to develop, from small-dimensioned pieces of timbers, a fairly big structure, such as may be employed for nailed built-up girders and nailed roof trusses. For light and moderately heavy roofs, nail-jointed roof frames are probably the cheapest and the bes :

Different ways in which load may be applied to the nails in structures are :

(i) Withdrawal from the side grain, as in the case of truss members and purlins ; and

(ii) Lateral load on side grain, as in the case of constructional joints in roof truss members.

In the design of nailed roof trusses, engineers usually come across lateral loads on side grain Safe ateral loads allowable on nails of different gauges used for connecting the wooden members are being worked out for different timber species at the F.R.I., Dehra Dun. Tentative values for 48 Indian woods are furnished in the following table.

TABLE XVII—1

Tentative values of lateral strengths of 7.5 cm and 10 cm nails of 9 S. W. G. in double shear

Sl. No.	Species of wood		For permanent constructions		For temporary constructions Strength per nail in kg Both for lengthening and node joints
	Botanical name	Trade name (Source in brackets for some species)	Strength per nail in kg		
			Lengthening joints	Node joints	
1	2	3	4	5	6
1.	**Abies pindrow*	Fir	80	20	120
2.	*Acacia nilotica* (*A. arabica*)	Babul	150	110	340
3.	*Albizia lebbeck*	Kokko	200	70	240
4.	*Albizia odoratissima*	Kala-siris	140	50	220
5.	*Amoora wallichii*	Amoora	190	60	190
6.	*Anogeissus latifolia*	Axlewood	200	100	290
7.	*Betula* spp.	Birch	130	120	230
8.	*Bischofia javanica*	Bishop-wood	130	65	180
9.	*Boswellia serrata*	Salai	120	50	130
10.	**Calophvllum* spp.	Poon	160	90	210
11.	*Cedrela* spp.	Gendhlipoma (Assam)	110	75	210
12.	**Cedrela torna*	Toon	150	100	180
13.	**Cedrus deodara*	Deodar	90	40	150
14.	*Chukrasia tabularis*	Chickrassy (Andaman)	240	80	270
15.	**Cinnamomum* spp.	Cinnamon	130	90	130
16.	*Cullenia excelsa*	Karani	115	50	190
17.	*Cupressus torulosa*	Cypress	60	50	180
18.	*Dipterocarpus macrocarpus*	Hollong	170	70	200
19.	*Dipterocarpus* spp.	Gurjan (Andaman)	190	90	180
20.	*Duabanga sonneratioides*	Lampati	150	40	120
21.	*Eucalvptus eugenioides*	Eucalyptus	170	100	300
22.	*Gmelina arborea*	Gamari	80	40	95
23.	*Gerewia tiliaefolia*	Dhaman (M.P.)	280	50	130
24.	**Grewia vestita*	Dhaman (U.P.)	130	50	240
25.	*Grevillea robusta*	Silver Oak	120	70	100
26.	*Lagerstroemia parviflora*	Lendi	190	50	260
27.	**Mangifera indica*	Mango	110	90	160
28.	*Mesua ferrea*	Measua	260	80	410
29.	**Michelia* spp.	Champa	130	90	200
30.	*Ougeinia oojeinensis*	Sandan	170	110	180
31.	**Phoebe* spp.	Bonsum	120	60	130
32.	**Pinus roxburghii*	Chir (U.P.)	110	100	160
33.	**Pinus wallichiana*	Kail	70	30	90
34.	*Pterocarpus dalbergioides*	Padauk (Andaman)	190	140	230

1	2	3	4	5	6
35.	*Pterocarpus marsupium*	Bijasal	150	120	170
36.	*Quercus* spp.	Oak (Assam)	280	100	380
37.	*Quercus* spp.	Oak (U.P.)	110	110	270
38.	*Schima wallichii*	Chilauni	175	95	100
39.	*Schleichera oleosa*	Kusum	230	160	400
40.	*Shorea robusta*	Sal (U.P.)	100	50	190
41.	*Syzygium* spp.	Jaman	150	120	250
42.	*Tectona grandis*	Teak (U.P.)	140	80	130
43.	*Terminalia bellirica*	Bahera	100	100	140
44.	*Terminalia bialata*	White chuglam	180	90	210
45.	**Terminalia manu*	Black chuglam	230	100	330
46.	*Terminalia myriocarpa*	Hollock	130	100	190
47.	*Terminalia tomentosa*	Laurel	160	160	290
48.	*Xylia xylocarpa*	Irul	230	60	330

Note.—Species marked * require no boring for nail penetration.

(b) *Wooden disc-dowels.*—A disc-dowel is a circular hardwood disc, generally tapered each way from the middle so as to form a double conical frustum. It is fitted into pre-bored holes, half in one member and half in the other. A bolt of wood or bamboo is passed through the centre of the disc to keep the jointed wood members from spreading apart. The dowel may be made of any hardwood which does not warp or split and is also not difficult to season. Nine species of wood suitable for manufacture of wooden disc-dowels and recommended by the F.R.I., Dehra Dun, have already been mentioned. The use of wooden disc-dowels makes it possible to have an all-timber construction, useful for chemical engineering purposes.

For larger spans, dowel-jointed construction has been found to be much superior to the conventional type of timber construction using steel gusset plates. Table XVII-2 gives the details and comparative costs of three different types of trusses :

TABLE XVII—2

Details and comparative costs of three types of trusses

Material	Steel truss		Timber truss with steel gussets and straps		Timber truss with disc-dowel joints	
	Quantity	Cost Rs.	Quantity	Cost Rs.	Quantity	Cost Rs.
Timber	—	—	0.623 cu m	55	0.595 cu m	53
Steel	499 kg	300	102 kg	60	—	—
Solid babul disc-dowel	—	—	—	—	100 Nos.	12
Bolts and nuts included above	—	—	39 kg	55	10 kg	15
Making	—	75	—	30	—	20
Total weight	499 kg	—	737 kg	—	583 kg	—
Total cost	—	375	—	200	—	100

[From *Indian Forest Records* (New Series), Utilization, Vol. 3. No. 1 : Timber roof trusses with solid wood disc-dowel joints.]

A recent construction with timber disez dowel joints is a 25-3-82 seen, three-hinged arch-type timber-trussed workshop building constructed by the Timber Engineering Branch, F.R.I. Dehra Dun (Fig. XVII-2).

(c) *Metal connectors.*—For span up to 30 m or even more, split rings are the usual connectors freely used for wood construction. Other important types of connectors are shear plates, toothed rings, and grid plates. These standard connectors are not available in Indian markets; but an improvised type developed at the F.R.I., Dehra Dun, has given fairly good results in laboratory tests with joints of different Indian timbers. A 30.5 m (100 ft.) span structure using bow-string type steel connectors jointed timber arch trusses has been erected at the F.R.I., by the Timber Engineering Branch and is being used as shed for different types of tests of small span trusses, beams, etc.

(d) *Glued joints.*—The use of glues for both latticed-type timber frames and laminated timber arches is, as earlier mentioned, the latest development in the field of timber construction, and this serves to overcom e limitations as regards the qualities of structural wood, its sizes, and the spans which could be covered by timber frames, etc.

For laminated members in inside locations, where they are protected from appreciable amounts of moisture and high humidity, case in glue is satisfactory. For outside and wet locations, where laminated members are subject to continuous wetting or intermittent wetting and drying, e.g., for exterior exposure or even inside buildings if high humidities are encountered for long periods, highly water-resistant adhesives, such as phenol-, resorcinol- or melamine-type resin glues, should be used.

The possibilities of constructing glued trusses and laminated units such as beams, joists and arches for large spans, and domes and shells for covering large unobstructed areas have been clearly established in many of the western countries. In India, such constructions are still in an exploratory stage but in due course, with the development of suitable indigenous glues and technical facilities and expertise, they are bound to prove popular with architects and builders.

(e) *Mechanically laminated joints.*—Because of non-availability of reliable glues, sophisticated gadgets and limitations regarding use of uniformly seasoned timber for glue laminated construction a, new technique has been developed where in small sized planks of secondary species are mechanically fastened together through ordinary nails and made into the required size of beams, joists, girders, purlins etc. to be used for various purposes. The technique has been developed keeping in view particularly, our Indian conditions of employment and availability of material. In this technique, secondary species timber planks of short lengths and ordinary wire nails are the only materials required which are easily available even in our rural areas, and employment is of ordinary skilled carpenters which are also available in the countryside.

Strength and scope of nail-jointed construction

Nail-jointed construction using short-length small-dimensioned timber, which has been under intensive investigation at the F.R.I., Dehra Dun, may be briefly discussed here.

Evaluation of strength.—The nature of the forces to which nails are subjected structural joints is different from that of the form to which nails are subjected in packing-cases. In the latter case, the pieces of wood are held together by the nails. The tendency of the contents of the box is to push these various wooden members apart. The nails now come into action and resist this force. The capacity to resist these side thrusts depends on the resistance offered by the timber to the nail when the latter is being withdrawn from the former and on the diameter of the nail. In other words, the withdrawal strength of a nail comes into action when the application of the external load is in a direction parallel to its penetration. In structural joints, however, the loads are generally applied in a direction at right angles to the direction of penetration of the nails, that is, the nails are laterally loaded. The following factors also play an important role in the strength of a structural nail joint :

(i) The portion of nail in the central member, subjected to a uniformaly distributed lateral load, deforms as though it were subjected to bending, being supported by two side members.

(ii) In an uncleanched nail joint, when the nail gets deformed and the slip occurs, the point of the nail is withdrawn a little from the side member and here the withdrawal resistance comes into play.

(iii) In addition to these two forces, the bearing resistance of the timber offered to the deformed nail has also to be considered. The species of timber will therefore have an effect on the resistance offered to the nail both in withdrawal and bearing.

The combined effects of all the above factors have been studied at the F.R.I., Dehra Dun, and, from the results, the values of lateral strength of the joints with different species of timber determined (vide Table XVII-1).

Factors determining strength and economy.—Factors that determine the strength and economy of a good structural nail joint are :

(i) Type of joint.

(ii) Species of timber.

(iii) Gauge or diameter of the nail.

(iv) Number of nails.

(v) Spacing of nails, end and edge distances.

(vi) Penetration of the nails into the main and side members.

(vii) Thickness of the main member and its relation to the side members or fish-plates.

(viii) Method of driving the nails and choice of nail point and shape of the nail.

(ix) Strength of nail-jointed structures under an applied load : (a) parallel to the grain of timber, and (b) inclined to the grain of the timber.

Recommended sizes of timber.—On the basis of tentative experimental results and demonstrations carried out at the F.R.I., Dehra Dun, the minimum sections of members and their lengths recommended for nail-jointed timber structures are as follows :

(i) Minimum thickness of any individual member: softwoods, 2.5 cm; hardwoods, 2.0 cm.

(ii) Minimum depths of members, for both hardwoods and softwoods: for chords, 7.4 cm; for web members, 3.7 cm.

(iii) Lengths of the members, 0.3 to 2.4 m.

Types of construction recommended.—The following types are recommended :

(a) Up to 4-m span—Monochord type with timber fish-plates.

(b) For spans above 4 m—Split-chord construction with or without timber fish-plates.

Specifications for fish-plates.—Timber fish-plates of the following minimum dimensions are to be used in nail-jointed timber trusses of both hardwoods and softwoods :

(i) Total thickness of fish-plates on either side of joint in a monochord-type construction. } $1\frac{1}{4}$ times the thickness of the member.

(ii) Total thickness of fish-plates and spacer blocks at any joint in a split-chord-type construction. } $1\frac{1}{2}$ times the thickness of the member.

(iii) The width of any individual space should not exceed eight times its thickness.

Advantages of the technique.—The advantages of nail-jointed construction using short-length small dimensioned timbers can be summarised thus :

(i) It can be used with safety even for big spans up to 20 metres.

(ii) Only ordinary wire nails are used for the structural joints.

(iii) The construction is easy and makes for overall economy.

(iv) Semi-skilled artisans under a competent carpenter can do the work.

(v) Due to the small-dimensioned timber used, the seasoning is easier and quicker, and defects and degrades due to seasoning are reduced to a minimum.

(vi) Preservative treatment is more effective in small-dimensioned stock.

(vii) A better grade of timber goes into the struture, as defective portions are eliminated in the selection of small-dimensioned short lengths for construction.

Modern timber engineering techniques in India

As a result of the pioneering work done at the F.R.I., Dehra Dun, timber-engineering technique using small-dimensioned short-length timber are becoming popular. The types of structures so far attempted in this country are briefly dealt with below.

(1) *Monochord and latticed type construction of roof trusses.*—Roof trusses are the most important of all the structural units in the field of timber construction. For small spans monochord type of construction with timber fish-plates would be quite economical and simple. Where stresses at the joints are heavy, it is difficult to have the required large sizes of fish-plates at reasonable prices.

Latticed or split-chord-type construction is generally practised for medium and large-span roof trusses. Besides the additional strength given to the connectors and better facilities to fix them in position economically, this type of connection requires relatively small sections for the members. For nail-jointed construction, sections ranging from 1.5 to 5 cm can advantageously be used. Even for dowel and splitring connectors, thicknesses ranging from 5 to 10 cm or more can be used. Fig. XVII-4 gives a general view of nail-jointed timber roof trussed Exhibition Hall put up by the Timber Engineering Branch of the F.R.I., Dehra Dun.

(2) *Lamella roofs.*—The lamella arch roof consists of a system of intersecting skewed arches made up of relatively short members (2×7 cm to 4×20 cm) called lamellae. These members are bevelled and bored at the ends and bolted together.

This type of roofing is ideal for auditoriums, halls and aeroplane hangars where large-span unobstructed spaces are desirable. Structures of as large as 60 m span can be conveniently and economically constructed with such a type of roof.

A beginning in this direction has been made in India at the F.R.I. One of such structures constructed with lamella arch roofs may be seen in Fig. XVII-3.

(3) *Solid web-type timber girders.*—This type of timber is built up of small sections of timber, and has a close similarity and resemblance to a steel-plate girder in constructional features although the two very much differ in their design methods.

Solid web-type timber girders are generally used for verandah beams, balcony girders, and arched roof frames of buildings with very large spans. These can be built as nailed or glued-and-nailed structures.

A modest beginning has been made at the F.R.I., Dehra Dun, in this respect by fabricating and erecting a number of such girders. The largest span so far covered is 21 m in the Timber Engineering Workshop. Fig. XVII-2 depicts the final stage of hoisting this girder in parts.

A 7.3—m-span solid web-type timer girder has been put to proof test since December, 1960. Maximum deflection noted is 0.5 cm. Another solid web-type girder of the same span was tested to destruction and this has taken more than 4½ times the design load.

(4) *Timber-concrete composite construction.*—The timber-concrete composite construction may be described as consisting of an R.C.C. slab over timber beams (solid or laminated), so rigidly interlocked with each other that the assembly is transformed into a single composite unit and is adequate for taking the design load. This type of construction can be economically used for flat roofs of buildings as well as for the bridge decking.

The design is based on the 'T' Beam theory according to which the web takes up the entire tension and the flange takes the compression. Timber beams, which are assumed to be governed by tension, form the web portion, whereas the R.C.C., which is strong in compression, forms the flange. In order to form a proper bond and take up the shear between the timber beams and the R.C.C. slab, shear keys in the form of iron spikes, shear rings, etc. are provided. These are partly driven or grooved into the timber beams before hoisting and are left projecting. This projecting portion is embedded in the R.C.C. slab above at site.

The structures having spans of 13.7 and 8.5 m, utilising this type of construction for balcony and roof, have been designed and constructed at the Forester's Training School, Pinjore and at the F.R.I., Dehra Dun, respectively.

Fig. XVII-5 depicts a view of one of these structures.

Long term proof tests for this type of construction using species of timber included in the three rational groups are in progress at the F.R.I.

Further investigations are also in progress using treated bamboo strips as reinforcement instead of the M.S. bars conventionally used. A few structures incorporating this techniqu ehave been erected and are under observations.

(5) *Timber bridges.*—There are different types of bridge super-structures to suit different spans, and these may be divided in the following classes :

(a) Girder type for spans upto 5 metres.

(b) Trussed-girder type for spans ranging from 5 to 8 metres.

(c) Truss types for spans ranging from 8 to 20 metres, classified as—

(i) King-post truss for spans ranging from 8 to 9 metres.

(ii) Queen-post truss for spans ranging from 9 to 10 metres.

(iii) Parallel-girder type (including Howe, Warren, etc,. types) for spans ranging from 10 to 20 metres.

(d) Solid arched rib type }
(e) Trussed arched type } For spans of over 20 metres

For all these types of timber trusses modern timber-engineering techniques utilizing short-length small-dimensioned timber pieces of secondary species could be economically employed.

A number of timber bridges of these types have been constructed in forest areas and elsewhere. Fig. XVII-6 shows one such model. A 13.7 m span dowel-jointed timber-trussed bridge of three spans has recently been constructed by the Public Works Department, Uttar Pradesh, in Saharanpur District.

Bridges are generally exposed to sun and rain. In our country, facilities for wood preservation are not yet available in many areas. Therefore, it is advisable to use only the heartwood of species of high natural durability and strength for bridge construction.

(6) *Prefabricated electric transmission posts.*—The conventional type of electric transmission supports, e.g., Hamilton type iron poles, tubular steel poles, R.C.C. posts and solid wood poles are not readily available, and this has led to the designing of a new type of composite prefabricated electric transmission post from nail-jointed small-dimensioned stock of secondary timber species. Timber planks of sections ranging from 2.5 × 7.5 cm to 4 × 18 cm and of lengths from 1 to 2.5 metres are profitably used in their fabrication. Designs based on the relevant strength characteristics of timber—viz., modulus of elasticity, tension parallel to grain, and compression parallel to grain—have been prepared at the F.R.I., Dehra Dun, for the following types of composite transmission posts :

(i) Low-and medium-voltage distribution posts.

(ii) 11 K.V. sub-transmission-line electric posts with narrow-base latticed structures.

(iii) 33 K.V. transmission-line electric posts with narrow-base latticed structures.

Fig. XVII-7 illustrates a transmission post prefabricated at the F.R.I., Dehra Dun, and erected at site.

It has been established that these composite timber transmission posts are more economical than the conventional type of wood poles at present in use and also compete fairly well with most of the conventional steel supports in use. Table XVII-3 gives an idea of the economy achieved by the use of the prefabricated timber posts instead of the conventional types of transmission poles.

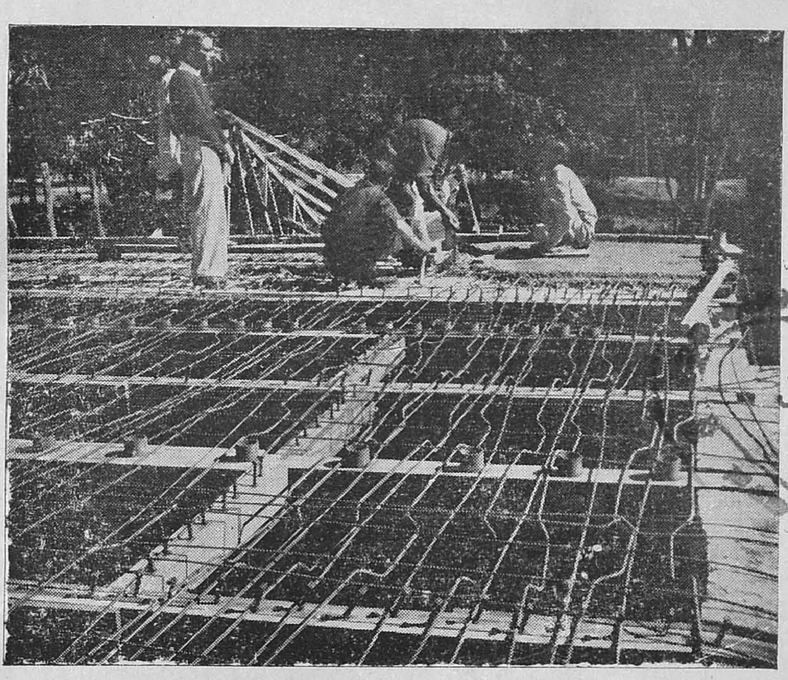

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Fig. XVII—5. Timber concrete composite construction.
(A 8.5 metres span flat roof being laid in timber concrete composite construction at Dehra dun).

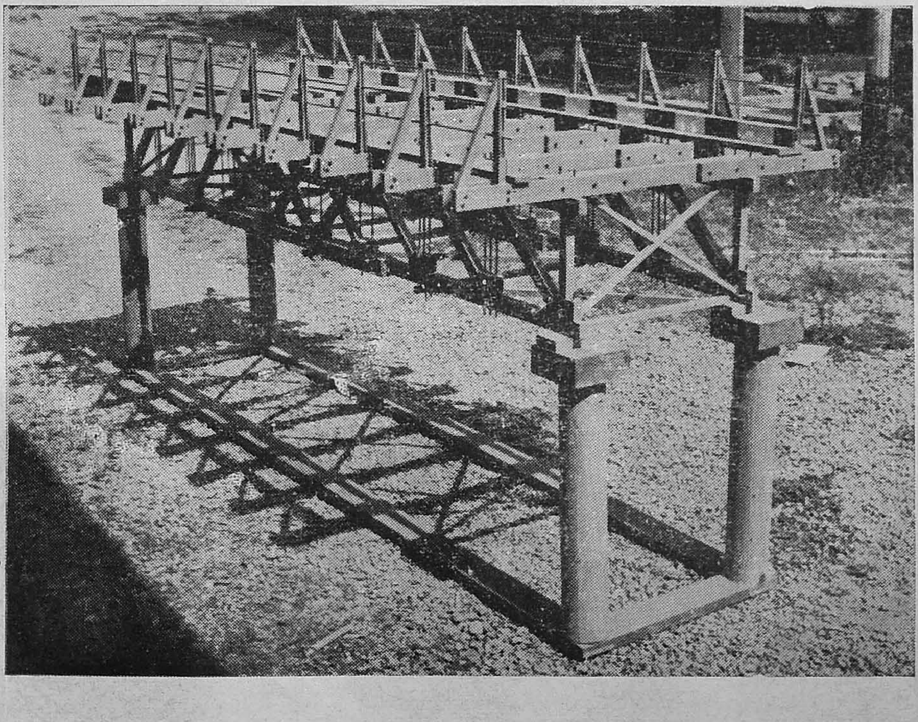

Fig. XVII—6. Timber bridges.
(Model of a 13.7 metres timber disc-dowel-jointed timber trussed bridge).

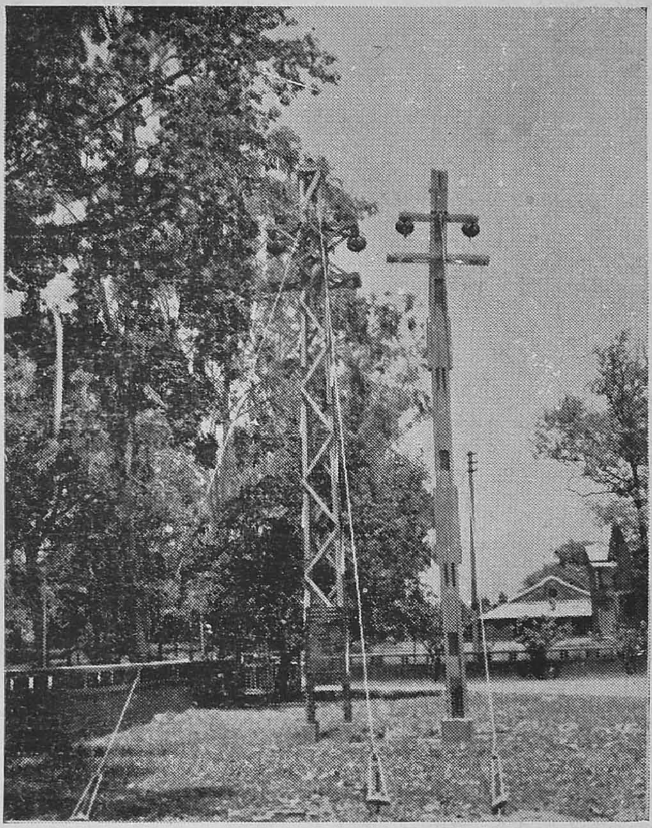

Fig. XVII—7. Prefabricated electric transmission post.
(11 K.V. sub-transmission line electric posts with narrow-base latticed structure).

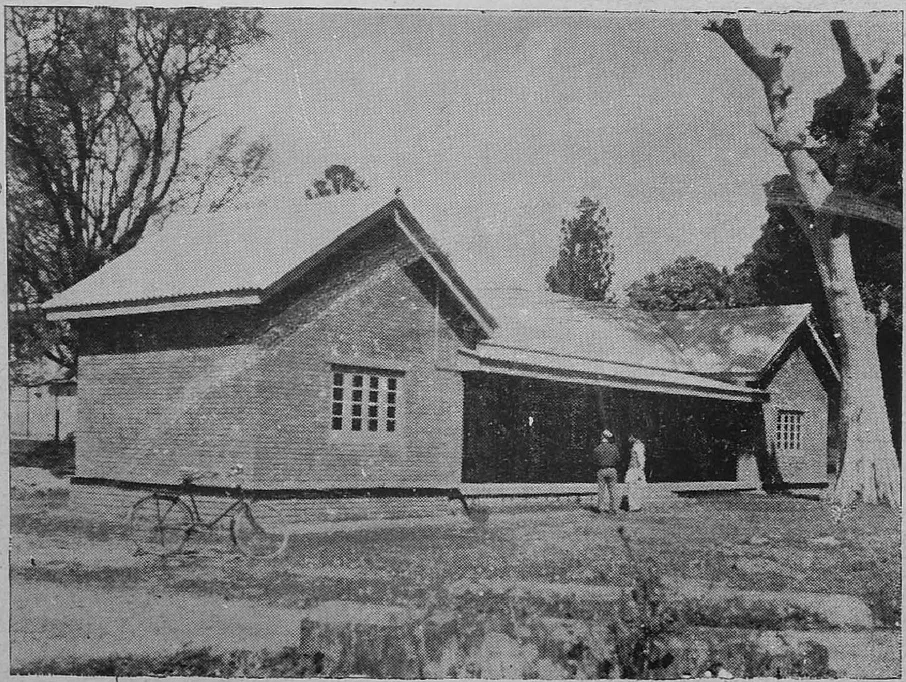

Fig. XVII—8. Anti-termite construction.
(Temite channel and shield for external protection).

TABLE XVII-3

Relative economy in different types of electric transmission supports

Sl. No.	Description of support	Cost per year of life at Dehra Dun Rs.	Increase in cost over new design of composite wood post per cent	Relative economy compared to conventional type of wood post per cent
1.	New design of composite wood post made of jointed planks	5.00	—	50
2.	R.C.C. pole with rectangular solid tapered section	6.05	21	39.5
3.	Tubular steel pole of three sections : Hamilton-type pole	8.41	68.2	15.2
4.	Conventional type of wood pole	10.00	100	—

(7) *All-timber structural units.*—In chemical factories there is a recurring problem of 'pittying' effect of acid fumes which adversely react on the metal structural part also. This necessitates replacement of these structural parts, e.g., steel roof trusses, steel columns, etc. In order to overcome such problems 'all timber' trusses and columns, etc., have been designed at the F.R.I., Dehra Dun.

In these structural components, use of even wire nails has been eliminated, and instead, timber and/or bomboo pins have been used, which are not affected by such reaction. Similarly in timber disc-dowel joints, M.S. bolts and nuts are eliminated and have been replaced with timber bolts and nuts.

(8) *Anti-termite constructional techniques.*—Termites have, of long, been causing enormous damage to timber and all possible measures should be taken to check their attack. Extensive experiments are being conducted at the F.R.I., Dehra Dun, for the last 15 years on various constructional measures by which termite attack on timber structures could possibly be eliminated.

The following 4 types of anti-termite constructional measures are recommended.

Type I (i) Internal prevention through termite proofing of flooring.
(ii) External detection through plinth coping and apron flooring.

Type II (i) Internal protection through termite proofing of flooring.
(ii) External protection through termite channel alround the periphery of the building (Fig. XVII-8).

Type III (i) Internal protection through termite proofing of flooring.
(ii) External protection through termite shields along the periphery of the building excepting at entrances and exits (Fig. XVII-8).

Type IV (i) Internal protection through termite proofing of flooring.
(ii) External protection through masonry channel and rat baffle walls around the periphery of the building.

Type IV above has the added advantage of checking attack of rodents also in addition to that of the termites.

Economics of modern timber-engineering techniques

The most significant contribution of modern timber-engineering techniques is the fact that they make for a more rational and economical use of timber in a field where it has been either most wastefully employed or not employed at all, viz., in construction. The permit of not only a vast variety of woods being used where hitherto only a few found favour, but also of small pieces being shaped for use into vast structures that formerly needed huge beames or were beyond the scope of conventional timber engineering. They have thus paved the way, along with other modern wood-based industries, for a more intensive management of forests through the use of secondary timbers at a stage when the primary ones, round which management has centred, were disappearing due to over-exploitation through ages. This is a circumstance that will considerably enhance the role of forests in our national economy.

TABLE XVII-4

Comparative costs of structures with different types of trusses

Sl. No.	Type of construction	Covered or plinth area sq m	Cost Rs.	Rate per sq m of covered or plinth area Rs.
I.	*For a span of* 6 *metres*			
	1. Prefabricated tubular trusses supported on steel stanchions	92.9	2,400	25.83
	2. King-post trusses supported masonry pillars	92.9	780	8.40
	3. Nailed-timber trusses supported on masonry pillars	92.9	720	7.75
II.	*For a span of* 9 *metres*			
	1. Prefabricated tubular construction	—	—	29.60
	2. Prefabricated steel sections supported by steel stanchions	139.4	3,700	26.54
	3. Queen-post truss supported on masonry pillars	139.4	2,100	15.07
	4. Nailed-timber trusses supported on masonry pillars	139.4	1,520	10.90
III.	*For a span of* 13.4 *metres*			
	1. Prefabricated steel section with steel stanchions	204.4	6,400	31.31
	2. Queen-post truss on masonry pillars	204.4	6,400	31.31
	3. Nailed-timber truss	204.4	2,500	12.23
IV.	*For a span of* 10-12 *metres* (From actual construction at Dehra Dun, for the Oil and Natural Gas Commission)			
	1. Cost of construction of one shed with tubular trusses	198	6,608	33.37
	2. Cost of construction of one shed with modern-type nail-jointed timber trusses	138	2,396	17.36
	(Saving in cost is 48%)			

Another equally important contribution these techniques would make is the saving in the use of steel and, to some extent, of cement on which conventional structural engineering has mainly relied. As steel and cement are commodities in short supply in this country, the economic import ance of an extensive resort to modern timber-engineering techniques cannot be exaggerated.

Apart from these general economic considerations, there is every indication from investigation already made at the F.R.I., Dehra Dun, that these techniques would make for tangible economies in costs of construction and thus recommended themselves as worth-while substitutes for conventional techniques in the field of construction. In the preceding Tables XVII-4 and XVII-5, a comparison is made of costs of construction with different types of trusses.

From the Tables XVII-4 and XVII-5, it may be seen that the nail jointed timber trusses incorporating modern timber-engineering techniques are far cheaper than the conventional type of timber trusses

(*Contd. on page* 288)

TABLE XVII-5

Statement of comparative costs of new-type design of timber trusses versus old-type truss design as seen in the Indian Forest College (I.F.C.) new building

Sl. No.	Span of truss and particulars	Spacings of trusses	Timber per truss	Timber for each bay of purlins	Nails for one truss	Bolts and flats	Approx. cost of one unit	Rate per sq m of ground area	Net saving per sq m in new-type designs	Saving on old type
		m	cu m	cu m	kg.	kg.	Rs.	Rs.	Rs.	per cent
1.	7.6 m New-type	3.7	0.125	0.441	4.1	—	266.75	9.58	6.57	40.7
2.	7.6 m Old-type at New I.F.C. Building	3.0	0.303	0.472	—	21.9	373.68	16.15	—	—
3.	10.1 m New-type for proposed Central Library Building (F.R.I., Dehra Dun)	3.7	0.319	0.425	6.8	—	352.50	9.58	7.86	45.1
4.	10.1 m Old-type at New I.F.C. Building	4.3	0.722	0.878	—	31.3	759.75	17.44	—	—
5.	15.3 m New-type for Food Grain Godowns	2.8	0.736	0.382	11.3	—	532.25	12.27	14.96	54.9
6.	15.2 m Iron truss at New I.F.C. Building		Angle iron and Flat iron							
		3.0	1.09 tonne	0.29 tonne	—	28.0	1,267.00	27.23	—	—

Note.—The following rates have been adopted in the calculations :

Finished timber at Rs. 353.15 per cu m.

Nails at Rs. 1.65 per kg.

Hardware at Rs. 804/- per tonne at controlled rates.

Bolts and nuts at Rs. 1.10 per kg.

Fabrication charges for timber truss at Rs. 106/- per cu m.

Fabrication charges for steel truss at Rs. 94/- per tonne.

(*Contd. from page* 286)

as well tubular construction. The average economy in favour of modern timber-engineering technique is as under :

(i) As compared to conventional type of timber construction = 45% (approx.)
(ii) As compared to steel trusses = 55% (approx.)
(iii) As compared to steel tubular construction = 48% (approx.)

REFERENCES

Hansen, H. J. 1948 Timber Engineers' Handbook ; John Wiley & Sons, Inc., New York.

I. S. I. 1961 Code of practice for use of structural timber in building (Material grading and design), IS: 883-1961 ; Indian Standards Institution, Delhi.

Kamesam, S. 1937 Special factors affecting timber design ; *Timber Development Series* No. 9 ; F. R. I., Dehra Dun.

Limaye, V. D. 1944 Detailed design of timber roof trusses made with wooden disc-dowel joints; *Indian For. Bull.* No. 123, Utilization, Manager of Publications, Delhi.

Limaye, V. D. 1943 Timber roof trusses with solid wood disc-dowel joints; *Indian For. Rec.* (N. S.), 3(1), Utilization ; Manager of Publications, Delhi.

Masani, N. J. 1956 Hardwood timber connectors and an improvised chine for making them for rural areas; *Indian For. Leafl.* No. 143, Timber Engineering; Manager of Publications, Delhi.

Masani, N. J. 1957 Economical roof truss designs through modern timber engineering; *Indian For. Leafl.* No. 152, Timber Engineering; Manager of Publications, Delhi.

Masani, N. J. 1958 Utility of modern timber engieering in India of today; Nasa Souvenir; Student Society of Architecture & Town Planning, Howrah.

Masani, N. J. 1966 Integrated schemss of saw mills, seasoning kilns and preservation plants for utilization of secondary species of timber in building trade and industries by modern timber engineering techniques of construction ; Manager of Publications, Delhi.

Masani, N. J. 1966 Rational classification of structural timbers, their choice and eonomy as applied to modern timber engineering techniques ; *A. Timber Engineering Handbook Series* No. 17; Manager of Publications, Delhi.

Masani, N. J. 1968 Wood's Challenge as a Structural Material; Manager of Publications, Delhi.

Masani, N. J. 1969 Lecture notes on timber engineering series 2; F. R. I., Dehra Dun.

Masani, N. J. — Timber Engineering in Europe and a Lesson for India (Cyclostyled); F.R.I; Dehra Dun.

Masani, N. J. & Bajaj, A.N. 1959 Wind pressure on buildings (rationalised); *Indian For. Rec.* (N.S.), 1(1), Timber Engineering ; Manager of Publications, Delhi.

Masani, N. J., Bajaj, A. N. & Govil, D. K. 1963 Timber-concrete composite construction ; *Timber Trade Journal;* Timber Merchants' Association, Calcutta.

Masani, N. J. & Gupta, R. K. 1966 Electric distribution and transmission posts from small dimensional timbers; *Engineering Industries*—A 'Bombay Market Supplement ; V.P. Agrawal, Bombay.

PART IV

DERIVED PRODUCTS OF WOOD

CHAPTER XVIII

PAPER AND RAYON

PAPER

The per-capita consumption of paper has been suggested as an indication of the degree of civilization a nation has attained. World development, as we know it, could certainly not have taken place without a means of communication between men in which speech is supplemented by written or printed records. Paper has undoubtedly been the principal medium for such records.

The origin of paper-making is somewhat obscure, but it is certain that it originated in China. Traditional Chinese records give the credit for its development to 'T' Sai Lun (about A.D. 105). One Chinese record states that "....he first made paper by pulping fishing nets and rags. Later he used the fibres of plants, and which proved sufficiently elastic in tension were used as the raw materials for paper. The raw materials were first well boiled and then beaten into a mash. They were then strirred into a pulp and spread on a straining frame or basket. When it had formed a thin tissue, the resultant paper was then pressed with heavy weights".

Till the end of the eighteenth century all paper was made by hand. Although the quality was usually high, the out-put was low. As the increase in population and the spread of industry, commerce and education lead to a corresponding increase in the demand for paper, efforts were made to replace the old methods by machinery. The most important of such machinery was the one made in 1799 by Louis Robert. Robert's paper-machine was improved by a London firm of stationers, owned by the brothers Henry and Sealy Fourdrinier. After many trials and much expense, a machine was erected at Frogmore in 1803. By 1830, one-half of the paper made in the U.K. was made on Fourdrinier paper-machines.

The shortage of fibrous raw materials had troubled paper-makers even before the introduction of paper-machines, but with the subsequent enormously increased capacity for production the problem became really serious and substitutes for rags were sought in all directions. In 1844, Keller, with the help of Voelter in Germany, developed the process for the manufacture of *mechanical wood-pulp*. The wood was held against a revolving grindstone, with a stream of water played on it to wash away the particles of fibre as they were scraped off the surface. Compared with the pulp that had been obtained from rags, this mechanical pulp was distinctly inferior as the fibres were shorter and less pliable, but the product was comparatively cheap and the potential supplies were large. In 1854, Watt and Burgess of the U.K. patented a process for producing pulp from wood by treatment with caustic soda. This *chemical wood -pulp* had a character entirely different from that of mechanical pulp. The non-cellulose portion of the wood was dissolved away leaving the fibres more or less whole and flexible, so that the pulp yielded a superior paper. Another chemical process for wood was that employing biusulphites patented by B.C. Tilghman in the U.S.A. in 1866. In 1860 Routledge introduced the use of espaito grass (*Stipa tenacissima*), cooked with alkali, into the U.K.

Fibrous Raw Materials Used For Paper-Making Abroad

The fibrous raw materials for paper-making are derived almost exclusively from plants, of which there are thousands of different species, ranging from common grasses to the largest trees. However, the number of species economically suitable as raw materials for paper-making is relatively limited.

Much of the structural portion of the plant is composed of cells. Cells are often too small to be visible to the naked eye, but in general they have a simple shape. Their walls are composed essentially of *cellulose*, a chemical compound with the empirical formula $C_6 H_{10} O_5$. Cellulose is a white fibrous substance, insoluble in simple solvents, and is resistant to dilute alkalis and dilute acids. Closely associated with the cellulose are non-fibrous carbohydrates called *hemicellulose* and an aromatic amorphous compound called *lignin*. In addition, the cells may contain such minor constituents as tannins, resins, waxes and mineral substances.

Those plant cells which resemble minute threads in shape, the length being many times greater than the breadth, are known as fibres. They are grouped closely together in the plant. The grouping is sometimes in separte bundles, distributed longitudinally in the interior of the plant stem or leaf and surrounded by a tissue of non-fibrous cells, as in straws and grasses. Sometimes, the fibres are grouped in the form of a closed ring situated just below the surface of the stem; these are the bast fibres, and the linen fibre from the flex plant is a good example. Alternately, the fibrous tissue maybe arranged in roughly concentric rings to form practically the whole of the plant stem, as in trees. In a very few cases, the fibres grow freely in the form of a hairy covering on seeds; the cotton fibre is the only important example of this type.

On the basis of their location in the plant, raw materials for paper-making may be classified roughly as follows :

Seed hairs	—	Cotton.
Bast fibres	—	Linen, hemp, jute.
Grasses	—	Esparto, straw.
Wood fibres	—	Coniferous and broad leaved woods.
Leaf fibres	—	Manila.

Cotton.—The cotton fibre, which is the purest form of natural cellulose available to the paper-maker, is a seed hair from the cotton plant. Almost the whole of the world's production of raw cotton fibre is used in the manufacture of textiles and the paper-maker therefore obtains his cotton fibre in the form of rejects from textile factories or as worn and discarded textiles. However, a small proportion of raw cotton, in the form of short-fibred linters, is used directly in the paper-mill. The cotton fibre is a flattened, twisted tube, on an average 25.32 mm long and 0.025 mm wide. As the original fibres consist of practically pure cellulose, the chemical treatment necessary to give a pure, strong, white fibre is relatively mild in nature.

Cotton imparts to paper made from it opacity, absorbency, strength, durability, permanence and good finish. Cotton is an extremely versatile fibre and can be used for the manufacture of a great variety of papers including blotting paper, currency note paper, paper for fine letter-heads, permanent editions of newspapers, paper for legal documents, bible papers, etc. As it is expensive, the use of cotton is limited to those papers that command an adequate price.

Linen.—The linen fibre is derived from the bast tissue of the stem of the flax plant (*Linum usitatissimum*), which is extensively cultivated in the United States of America, Russia, Hungary, France, Belgium and Ireland. The fibre is used largely for the manufacture of textiles, so that the paper-maker obtains most of his linen fibre in the form of rejects from the textile fibres and as worn textiles.

The linen fibre has a rounded section and a tubular shape, with thick walls and a narrow central canal. The average dimensions are about 25 mm length and 0.02 mm diameter. Because of its high cost it is generally used for the highest grades of papers. The important properties given by this fibre to the paper sheet are strength, toughness and durability.

Hemp (*Cannabis sativa*).—Hemp is the bast fibre of an annual shrub grown extensively in India, Russia and America. The crude fibre liberated by retting contains about 75 per cent of cellulose; it usually comes for paper-making in the form of spinning waste, twine, ropes, etc. The ultimate fibre is about 20 mm long and 0.02 mm in diameter and is very similar to linen in paper-making behaviour. It is used for strong papers like bank-notes, cigarette and other strong tissues, insulating paper, and strong wrapping-papers.

Jute.—Jute is a bast tissue of two annual plants, *Corchorus capsularis* and *C. olitorius*, grown extensively in India. The fibre liberated by retting contains about 60 per cent of cellulose. It is extensively used for making coarse cloth and bagging. For paper-making it comes in the form of used sackins. The ultimate fibre is 2 mm long and 0.02 mm in diameter. It is mainly used in the manufacture of strong wrapping-papers.

Esparto.—The source of this fibre is the leaf of the esparto grass (*Stipa tenacissima*), which grows in southern Spain and in North Africa. The true fibres are located in bundles within the leaf and amount to over 45 per cent of the air-dry weight of the grass. They are liberated by cooking the grass under

pressure with caustic soda solution. The actual fibre has an average length of 1.5 mm and a diameter of 0.013 mm. As the fibre is small and flexible, it confers on paper a closeness of texture and smoothness of surface that are unique. The grass is used for the production of good-quality writing and printing papers.

Straw.—Straw fibres are obtained from the steams of various cereal plants such as wheat, oat, barely and rye, which are cultivated primarily for the grain they yield. The averge fibre is 1.5 mm long and 0.015 mm in diameter. Straw, cooked with caustic soda and bleached, is used, mixed with longer fibres such as wood-pulp or rag, in the production of good-quality writing and printing papers. Straw, cooked with lime to make a crude brown pulp, is used in the manufacture of straw-boards.

Wood.—Wood fibres are most widely used for paper-making. Wood fibres are obtained from either coniferous or broadleaved trees, chiefly from the former. About 97 per cent of the world's paper and board is made from wood-pulp and 85 per cent of the wood-pulp used is from coniferous trees, mainly spruces (*Picea* spp.). firs (*Abies* spp.) and pines (*Pinus* spp.).

The fibre dimensions and chemical composition of conifers are as follows :

(1) Mean fibre length, in mm		3-3.5
(2) Mean fibre diameter in microns		30-40
(3) Mineral matter	%	1-2
(4) Extractives (in water, alcohol, etc.)	%	4-12
(5) Cellulose	%	40-45
(6) Hemicellulose	%	15-20
(7) Lignin	%	26-30

The other wood fibres are from broadleaved trees. The hardwoods used in paper making include poplar (*Populus* spp.), aspen (*Populus tremula*), birch (*Betula* spp.), beech (*Fagus* spp.), chestnut (*Castanopsis* spp.) and eucalypts (*Eucalyptus* spp.).

Manila.—Manila fibre occurs in the leaves of ***Musa textiles***, a plant of the plantain family that grows in the Philippine Islands. The crude fibre contains about 65 per cent of cellulose and is used for making ropes. The ultimate fibre is about 6 mm long and 0.025 mm in diameter. It is very even and regular, with relatively thin walls, and gives an extremely tough, almost untearable, sheet. It is used chiefly in the manufacture of stencil, insulating, envelope and wrapping-papers, for which great strength is required and a high white colour is not necessary.

Selection of Fibrous Raw Materials for Paper-Making

There is no industrial country, with pulp, paper and board industry, that has not shown interest in one way or another in the use of other fibrous raw materials as substitutes for their conventional raw materials.

Once the paper-maker leaves the area of rag and textile waste and enters the field of primary raw materials, he comes in contact with an astonishingly large number of grasses, woods and agricultural wastes which he can consider as raw material resources for making pulp, paper and boards. When we remind ourselves that the fundamental basis of the industry has to be some kind of waste, man's or nature's and enter the field of nature's waste, we can formulate a whole series of economic and technical limitations, imposed by nature and by man, each in succession reducing the area of selection of raw material. The selection of these raw materials from nature's waste should be on the following basis ;

A. *Economic considerations*

(1) Plentiful and sustained supplies of the material must be available in order to ensure adequate and uninterrupted supplies for mills dependent on it.

(2) The total cost of extraction and collection of the material and its transport to the mill site must be such as the industry can bear. Since only the cheapest materials can be used for paper-making, those which grow in inaccessible regions or are widely and thinly scattered, those for which cheap means of transport are not available, and those which find better and more profitable uses in other trades and industries are ruled out of consideration.

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(3) Regularity of supplies as regards both quality and quantity of raw material must be ensured. It is obviously undesirable to start an industry unless this requirement is guaranteed.

(4) The cost of processing (including chemicals, steam and power) depends on the purpose for which the paper is required. A paper having exceptionally good properties can sometimes command a very high price, so that the cost of production is a minor consideration in such a case.

(5) Supplies of raw meterial should be easily replaceable. It is obviously a bad policy to build a factory if the supply of an existing raw material cannot be replaced when once exhausted. Fortunately, plants are in the category of raw materials which are replaceable.

B. *Technical considerations*

(1) Ease with which the non-fibrous constituents can be removed.

(2) Quality of the pulp produced with special reference to the particular pulp-consuming industry in view.

(3) Yield of pulp.

(4) Consumption of chemicals, steam and power for pulp production.

On applying the above check list, of the millions of species in the plant kingdom those suitable for making paper are reduced to a few.

Fibrous Raw Materials for Paper-Making in India

The raw materials used in India for paper-making are briefly dealt with below :

Bamboo.—The main fibrous raw material used in India at present is bamboo. The investigations carried out at the Forest Research Institute, Dehra Dun, first on a laboratory scale and then on a pilot-plant scale, established its suitability. The utilization of bamboo has, however, almost reached the maximum limit and now we shall have to depend on other raw materials for expanding our paper industry.

Bamboo grows extensively in Assam, Bengal, Bihar Orissa, Madhya Pradesh, Maharashtra, Andhra Pradesh, Tamil Nadu, Mysore and Kerala. The main species of bamboo used today for paper-making are : *Bambusa arundinacea, B. balcooa, B. Nutans, B. tulda, B. vulgaris, Dendrocalamus hamiltonii, D. strictus, Melocanna bambusoides, Ochlandra rheedii, O. travancorica,* and *Oxytenanthera monostigma.* Bamboo is being pulped by the sulphate process by most of the mills ; one mill, however, is using the sulphite process. Bamboo is used for almost all the common varieties of papers like writing, printing and wrapping papers and as part of the furnish in newsprint.

Sabai grass (*Eulaliopsis binata*).—Sabai grass continued to be a major source of raw material for the Indian paper industry for almost half a century. Limited supplies of grass and the rising cost of colletction, however, made it eventually imposible to sustain the growing paper industry in the country on this as the main raw material. Now sabai grass occupies the second position in the inventory of Indian paper industry.

Sabai grass is a perennial tufted grass found in many parts of Northern India. Extraction of the grass commences in November and extends up to March-April every year. Sabai grass is normally pulped by soda process. A few mills have started using sulphate process for pulping it. It is mainly used for the manufacture of writing and printing papers.

Bagasse.—Bagasse is the waste fibrous product remaining after crushing sugarcane and extracting juice. Bagasse is steadily gaining popularity as a paper making material and is sure to make a great contribution in the production of paper and paper boards. At present the major use of bagasse is as fuel in the sugar mills.

For making paper, fibres are first separated from pith and then pith-free fibres are used, whereas for boards the whole bagasse is used. In India, bagasse is used as a part of the furnish by several mills for making writing and printing papers. It is also being used by strawboard mills for manufacture of strawboards.

Woods.—Wood available from the forest for conversion into pulp and paper can be broadly classified into two types. Wood of coniferous trees is generally termed as softwoods. Wood of broadleaved trees is known as hardwoods.

(1) *Softwoods.*—As the extraction cost of conifers in India is very high, and it has other better utilization, e.g., as sleepers, this raw material has not been used much for paper-making. Twisted chir pine (*Pinus roxburghii*), which is of no use as timber and is often unsuitable even for use as firewood, is being used by the industry as a part of the furnish by a few mills for the production of kraft papers. Sawmill waste is also being utilized for the production of bleached paper. A little quantity of softwood is also being used for the production of groundwood pulp used as a part of the furnish in manufacture of boards.

(2) *Hardwoods.*—The tropical hardwoods occurring throughout the length and breadth of India are the ones which , if exploited discriminately, could help in increasing the production of paper in the country.

Salai (*Boswellia serrata*) is being used in the only newsprint mill in India as ground wood pulp for manufacture of newsprint. In the furnish a mixture of 60 per cent salai groundwood and 40 per cent bamboo chemical pulp is being used. Newsprint manufactured from salai and bamboo compares favourably with the imported newsprint manufactured out of softwoods except for shade.

A few mills have started using mixtures of hardwoods, as a particular species is seldom available in sufficient quantities and in concentrated stocks for economic exploitation. In our forests, in the natural state a large number of species of hardwoods grow in mixture and hence utilization of mixed hardwoods is justified. One mill is using mixed hardwoods, mixed with twisted chir pine, for the manufacture of kraft papers. One mill is using mixed hardwoods along with bamboo for writing and printing papers.

Jute sticks.—Jute stick is the woody residue left after extraction of the bast fibre of the jute plant (*Corchorus capsularis* or *C. olitorius*). Jute is cultivated mainly in Bengal, Assam, Tripura, Bihar, Orissa and Uttar Pradesh. So far jute sticks are mainly used for thatching roofs and fencing gardens and as a fuel. A substantial amount is just allowed to rot. Two large paper-mills in West Bengal have been using jute stick pulp in making writing and printing papers.

Mixed grasses.—Mixed grasses, as they grow together in the forests, have also been used commercially for production of writing and printing papers as a direct result of investigations carried out at the Forest Research Institute, Dehra Dun. As selective harvesting of grasses is uneconomical and also reduces the quantity of grass available per unit area, the use of mixed grasses is the only solution of overcome the shortage of raw material.

Waste paper.—The recovery of waste paper is traditional in the paper and paperboard industry. The utilization of waste paper supplements to a great extent the overall fibre requirements in any country, and every possible attempt should be made to recover waste paper for its being converted into paper, specially in those regions where it is difficult to get sufficient and cheap raw materials for the manufacture of paper and paper boards. In India waste paper is mainly used for the manufacture of paper boards. White waste paper is also used sometimes for the manufacture of writing and printing papers.

PROCESS OF PAPER-MAKING

The process of paper-making consists of five main steps : (1) Pulping; (2) Pulp cleaning; (3) Pulp bleaching; (4) Stock preparation; and (5) Sheet formation.

(1) *Pulping*

The paper industry is by far the largest consumer of pulp. Pulp for paper and chemical uses is defined as a crude fibre material of one kind or another, produced chemically or mechanically from fibrous cellulosic raw materials, from which, after suitable treatment, are made paper, paper boards, rayon, etc. Pulps can be produced today in many different yields depending on the suitability of the various raw materials used and the various end products.

Pulping is the process of isolation of cellulosic fibres from raw materials. The following processes are used :

(i) Mechanical process.

(ii) Chemical process.

(a) Alkaline process
(b) Acidic process

(iii) Semi-chemical process.

(i) *Mechanical process.*—It is possible to use purely mechanical methods for disintegrating the wood into fibrous state without the use of chemicals. This process involves the wet grinding of wood into a fibrous mass by means of a revolving grinding stone. Logs of debarked wood are held against the revolving stone and, as the stone grinds the wood, a stream of water is spread on the stone to carry the pulp away. The logs are held against the revolving stone in transverse fashion, with the length of the log parallel to the axis of the grinding stone, to obtain long fibres. The forces of friction tear fibres from the logs and the fibres are carried in the grooves of the grinding stone to the grinding pit. Cheap power is essential for economical operation. Mechanical pulp differs from chemical pulp in that it contains practically all the lignin of the original wood and the fibres do not exist as individual fibres but rather as fibre bundles and fibre fragments.

The pulp flowing out of the pit contains much coarse material such as splinters. Coarse materials, are removed by a bull screen which is a tray-shaped metal plate having perforations of about 6 mm diameter. The rejects are further processed in disc refiners. The refined pulp is further returned to the screened pulp before it is passed through a subsequent complex screening and cleaning system to ensure that shives, splinters and sand particles do not pass into the paper machine. As screening is done at a low consistency, the pulp is further thickned by thickeners or deckers. The water removed in the process of thickening is re-used in screening.

Normally light-coloured conifers are preferred for making mechanical pulp. Certain hardwoods like poplar and eucalypts are also used. In India salai wood is used largely for making mechanical pulp.

The main use of mechanical pulp is in manufacture of newsprint. The advantages of using mechanical pulps in the furnish are that the cost of production is reduced due to lower cost of production of mechanical pulp and that it improves printing. The disadvantages are, however, that it affects the colour, strength and durability. Pulp yield obtained by mechanical pulping process is generally 90-95 per cent and requires about 1,100-2,000 KWH power per tonne of pulp.

(ii) *Chemical process.*—Cemical pulping is a process in which lignin, the binding material of vegetable fibrous raw materials, is removed by digesting the raw materials, cut to suitable size, in the presence of chemicals. If the cooking chemical used is alkaline in nature, the process is said to be 'alkaline process' and if acidic 'acidic process'.

(a) *Alkaline process.*—The two principal alkaline processes used for pulping are 'soda process' and 'sulphate process'. In both the processes sodium hydroxide is used as major cooking chemical. While, however, in soda process only sodium hydroxide is used, in sulphate process sodium sulphide is also used in addition. The use of the soda process is restricted to pulping grasses and agricultural residues.

Pulping is carried out in welded steel digesters (Fig. XVIII-1) usually without lining. The digesters are heated either directly or indicrectly (circulating the cooking liquor through a heat-exchanger). Digestion is carried out under pressure. The conditions of cooking are precisely controlled according to the type of raw material used and the quality of pulp required.

When a cook is complete, the contents of the digester are blown by the pressure inside it into a blow tank. This procedure helps to separate the fibres in the very soft chips. The pulp is then washed in diffusers or washers (Fig. XVIII-2). After successive washings the fibres become free of black liquor. The black liquor is sent to the soda-recovery unit to recover the chemicals and pulp is processed further.

The main advantages of sulphate pulping can be summarized as below :

(1) Maximum flexibility with regard to species.
(2) Shorter cooking periods.
(3) The bleaching of the pulp to high brightness levels.
(4) Absence of pitch problems.
(5) High pulp strength.

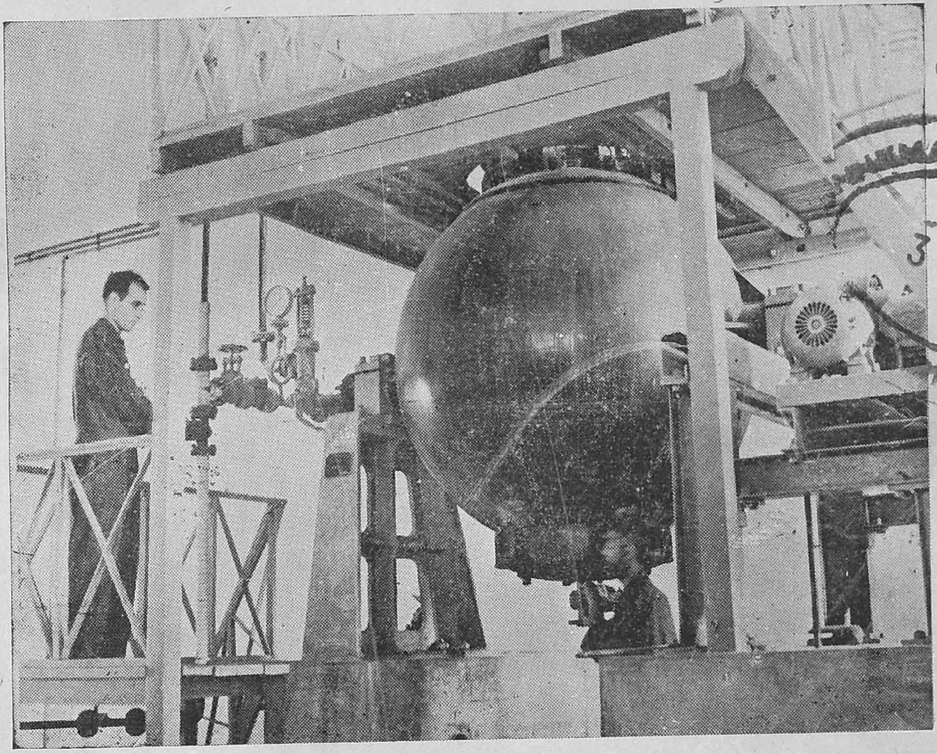

Fig. XVIII—1. Rotary digester.

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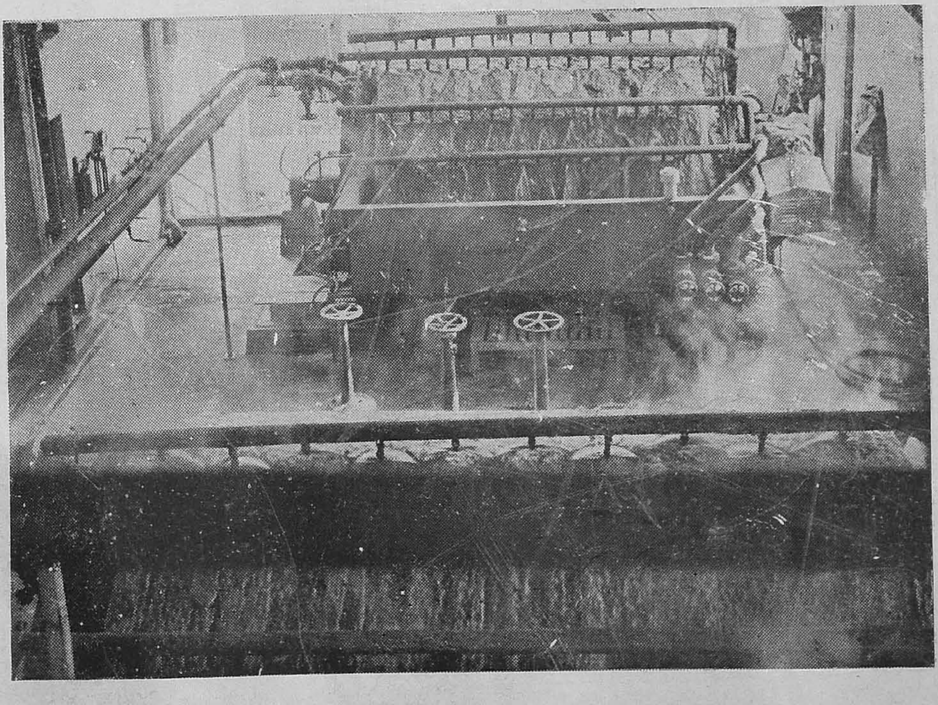

Fig. XVIII—2. Drum washer.

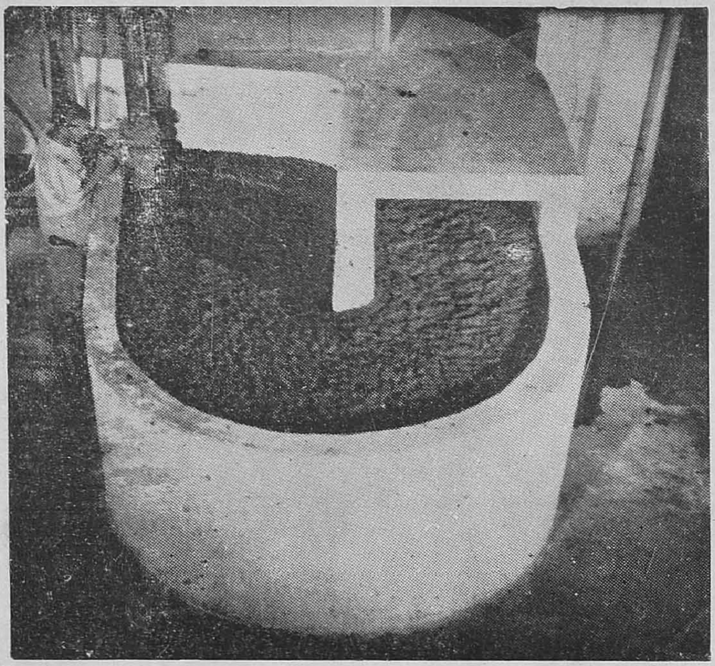

Fig. XVIII—3. Beater.

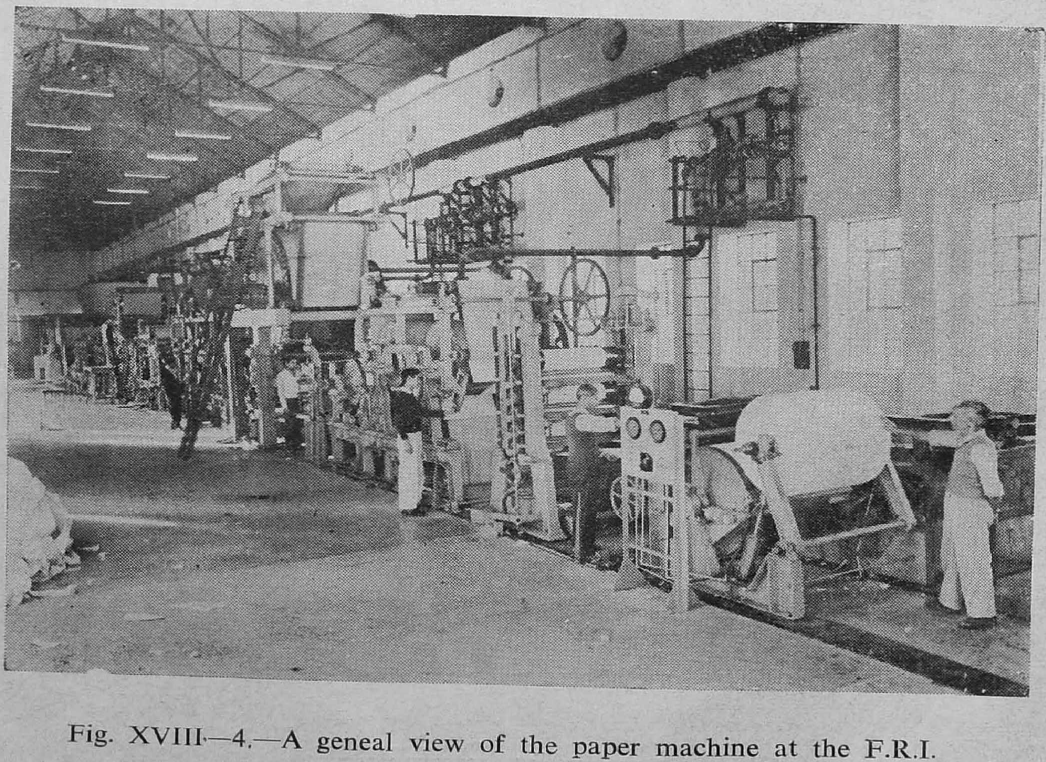

Fig. XVIII—4.—A geneal view of the paper machine at the F.R.I.

(6) Production of valuable by-products in the form of tall oil and turpentine.
(7) Efficient chemical and heat recoveries.
(8) Relatively low stream pollution.

(b) *Acidic process.*—Fibrous raw materials are digested with a cooking liquor composed of calcium bisulphite and a considerable amount of excess sulphur dioxide. In this case cooking liquor is very acidic. This process is termed as 'sulphite process'. Sometimes, digestion is carried out with a cooking liquor composed of magnesium or ammonium bisulphite with a slight excess of sulphur dioxide. For these processes, the steel shell of the digester is protected by an acid-resistant brick-lining.

The cooking liquor is prepared by burning sulphur or iron pyrites in air to form sulphur dioxide. Sulphur dioxide is passed through absorption towers containing limestone over which water flows. Sulphur dioxide dissolves in water forming sulphurous acid that dissolves lime as calcium bisulphite. An excess of sulphur dioxide is kept in the cooking liquor.

The waste liquor from the sulphite process is usually discharged into a stream. Recovery of chemicals is normally not done due to several reasons such as the deposition of calcium compounds. A few mills use the waste liquor as a source of chemicals such as lignin, vanillin, alcohol, etc., or as a binder for roads or as a tanning agent.

(iii) *Semi-chemical process.*—The idea of semi-chemical pulping for high-yield production of fibrous pulps is not new and was known as early as 1920, but this process has become one of much more interest now. Semi-chemical pulps are considered to include those pulps which are produced by a light chemical treatment followed by a mechanical fibrization. The chemical treatment may employ conventional pulping chemicals to help in the softening of the chips and some removal of lignin. Semi-chemical pulps ordinarily include neutral sulphite semi-chemical high yield sulphate, high-yield sulphite, cold soda, and mechano-chemical pulps.

The use of high-yield sulphate is well established for conifers, and now this process is also being used for hardwoods. The use of high-yield sulphite pulp for the manufacture of newsprint was established some years ago, and in recent years the yields are reported to have been increased in some instances to as high as 70 per cent.

Unbleached neutral sulphite semi-chemical pulps from hardwoods are being extensively used for the production of corrugating medium. Bleached neutral sulphite semi-chemical pulps made from hardwoods have high strength properties and are being used successfully for printing, writing and other fine papers and paper-boards. The pulping chemical in this case is a solution of sodium sulphite and sodium bicarbonate. Sodium bicarbonate acts as a buffer.

The cooking chemical is the same, viz., sodium hydroxide, in the cold soda and mechano-chemical processes, but in the mechano-chemical process the chemical and mechanical defibrating actions are given simultaneously. The cold soda process has been found very successful for hardwoods, while the mechano-chemical process is better applicable for agricultural residues. Cold soda process is more successfully applicable on those dense hardwoods which are not suitable for groundwood pulping, specially for newsprint-grade pulps.

(2) *Pulp cleaning*

The digested pulp contains a proportion of material which should be removed before further treatment. This is quite essential as pulps may contain knots, shives, dirt, grit, etc., which may give trouble in further processing. Pulp cleaning is done purely by mechanical means.

The first step in pulp cleaning is screening over flat screens. The separation process employed in screening depends on the difference in dimensions of the fibres and the material to be rejected. It is practically impossible to achieve proper screening in one stage; hence the operation is done in two or more stages. In the actual screening operation, pulp of a low consistency flows over a perforated metal plate which allows the accepted fibres to pass through and retains the rejects. The dimension of the perforations varies greatly, depending upon several factors such as the type of pulp, the type of cleaning required, and the number and arrangement of screening equipments provided.

Normally, in the first stage only knots are removed over coarse screens. In the next stage fine screening is done to remove shives. Fine screening is nowadays done by centrifugal screens. After fine screening, small particles of dirt, grit, etc., are still to be removed. In the earlier days, pulp of a low consistency was flown over sandtrap or riffler, generally a wooden channel, in which particles heavier than pulp were removed by settling. Later on, several types of centrifugal cleaners came into existence, in which the differences in densities of dirt and fibres are magnified by centrifugal force, thereby increasing the efficiency of separation.

(3) *Pulp bleaching*

Bleaching of pulps is a process in which the remaining impurities that impart a poor colour to the pulp are either removed or decoloured, in a systematic way step by step, to a desirable stable brightness. Bleaching is accomplished by oxidizing or reducing agents. Most common commercial chemical agents are chlorine and its compounds.

Nowadays cooking and bleaching are considered to be two steps in the isolation and purification of cellulosic fibres from a cellulosic raw material. Bleaching is a process where selective treatments, not possible in cooking, are given to remove the impurities and minimize the degradation of cellulose. Pulps can be bleached in a single stage or in several stages. In single-stage bleaching, calcium hypochlorite (bleaching powder) is mostly used, while in multi-stage bleaching chlorine gas, calcium hypochlorite, and chlorine dioxide are used. Nowadays, peroxide and hydrosulphides are normally used in semi-chemical and groundwood pulps for improving brightness

(4) *Stock preparation*

This comprises : (a) beating, (b) sizing, (c) loading, (d) colouring, and (e) use of other additives.

(a) *Beating.*—Cellulose fibre must be subjected to mechanical treatment before it can be formed into a saleable sheet of paper. The treatment may be applied in the form of bruising, cutting or crushing action on the fibre. The terms 'beating' and 'refining' are used for the mechanical treatment given to fibres in paper industry. A very considerable quantity of power is used for beating. For most of the types of paper about 200—1000 WH per tonne are required.

The principal effects of beating are mostly physical. The important effects are :

(i) Fracture and partial removal of cell wall.
(ii) Decrease in fibre length.
(iii) Increase in fibre flexibility.
(iv) Formation of fibrills.
(v) Increase in external specific surface of fibres.
(vi) Retardation of drainage.

These effects bring about a radical change in the physical properties of paper. The major effects on paper are :

(i) Increased beating increases bursting strength, tensile strength, folding endurance, smoothness, and rattle.

(ii) Increased beating reduces tearing strength, bulk, porosity, opacity, and dimensional stability. Thus it can be seen that the physical characteristics of paper mainly depend upon beating. The beating can be adjusted to suit the requirements of the end use of paper. In fact, by altering the beating procedure many varieties of paper can be manufactured from the same raw material.

The equipment used for beating is known as beater. For nearly two centuries since the first beater was invented, this piece of equipment has served the paper industry without any major modification. The charge has often been made that this equipment is crude and inefficient. This is true to some extent, and considerable work has been done to replace it. To an extent beaters have been replaced by refiners in the manufacture of newsprint, kraft, writing and printing papers, but they continue to be widely used for speciality papers and in small mills.

The Hollander beater is the oldest type of beater that can still be seen in the industry (Fig. XV-3). It consists of a tub having two parallel sides and semi-circular end. The tub is divided in to two channels by a partition known as 'midfeather', The pulp suspension is circulated with the help of a barred roll. The roll throws the pulp suspension over a crest known as 'backfall', the floor of which is elevated to the centre line of the roll. The back fall gives the stock a hydrostatic head so that pulp suspension can travel in the channel. Below the roll a barred plate is inserted so that the fibres may get mechanical treatment.

(b) *Sizing.*—Paper which is more or less impervious to the penetration of inks is said to be 'sized papers', whereas absorbent papers are called 'waterleaf papers'. Certain chemicals are added to size the paper. Rosin soap along with aluminium sulphate, which is known to paper-makers as alum, is the most widely used material for sizing. Rosin soap is generally made by saponifying rosin in alkali. In addition to rosin soap, wax emulsions are also used for sizing. Extreme care is taken while using wax emulsions to avoid wax spots on paper.

(c) *Loading.*—Addition of non-fibrous mineral matters to stock prior to sheet formation is known as 'loading'. Materials used for loading are known as 'fillers'. Formerly, addition of mineral matters to pulp suspension was thought to be adulteration. As the technology advanced, it was realized that addition of fillers is very essential for certain grades of paper like printing papers. Common fillers used by the industry are china clay, talc powder, and titanium dioxide. Other fillers like calcium carbonate, barium sulphate, etc., are used for special purposes.

Fillers are used to improve the printing surface and the absorption of printing inks, to give a better finish, higher opacity, a close and even appearance, flatness, and softness, and to improve dimensional stability in changing atmospheric conditions. They often improve the brightness too, but the strength and sizing of paper are reduced.

Fillers may be added to the beater in a dry condition or after making a slurry in water. The latter method is normally practised by the industry.

(d) *Colouring.*—Almost 90 per cent of the paper produced today is coloured to some extent. Colouring is normally done in beaters. Both insoluble pigments and water-soluble dyes are used. Dyeing of paper to correct shade depends on a number of variables in which selection of the suitable dye, the amount to be added, and the brightness of pulp are of major importance.

(e) *Use of other additives.*—Other additives like starches, vegetable gums, synthetic hydrophilic materials, and resin emulsions are also used in the industry. Generally, these additives are used to give special characteristics to a paper. They are generally added in the beater and are called as 'beater additives'. Sometimes these additives are added at places other than beaters, generally at the fan-pump or head box of the paper machine. When used in this way they are termed as 'wet end additives'.

(5) *Sheet formation*

After the pulp has been treated in stock preparation, it is taken to the paper machine for conversion into paper. There are two principal types of machines : (i) the Fourdrinier machine, and (ii) the Cylinder mould machine.

The beaten stock is taken in a chest from where it is passed through cleaning equipments after reducing its consistency. Cleaned pulp of a very low consistency, normally around 0.5 to 1.0 per cent, is fed to a flow box and slice for the maintenance of an even flow, free from eddies and cross currents across the width of machine.

In the Fourdrinier machine a long endless wire on which pulp travels is used. Water is drained leaving a wet web of paper. To improve the formation of paper, the wire is given a shaking motion towards the flow-box side. The wire is supported by a number of small-diameter rolls known as 'table rolls'. In addition to supporting the wire, these table rolls help in removing the water from wet web. Although water is removed to a large extent through the wire by gravity and by table rolls, further removal of water takes place when the wire moves over several suction boxes. Water marks or laid marks are impressed on the paper web at this stage by means of a skeleton roll, known as 'dandy roll' which is inserted between the suction boxes. The last roll which drives the wire is

known as the 'couch roll'. The function of the couch roll is to further remove water and make the wet web sufficiently strong so that it can be passed over to the next section, viz, the press section.

In the cylinder mould machine, the stock is picked up on a wire-covered cylinder roll which rotates in a vat containing stock of a low consistency. The mat is then transferred to a felt which carries the mat to the press section. For making thick boards, a number of vats are used and the wet mat of one mould laminates with the wet mat of the next mould.

The wet web either from the Fourdrinier wire or the cylinder mould is fed to the press section. The wet web is carried on woollen felts and is pressed by several presses before the sheet is transferred to the drying section of the machine. In the drying section the wet paper web, carried on an endless cotton, asbestos or synthetic felt, passes over several hollow, steam heated cast-iron rolls. Several driers are given to remove all the water and to make the web dry. To impart the requisite degree of smoothness to paper, the dry web is passed through a stack of cast-iron rolls known as the 'calender'. After calendering it is rolled over spools.

In some cases, one side of the paper is given high polish. To impart this, the web containing sufficient moisture is pressed over a single, highly polished, steamheated, large cylinder, known as 'M.G. cylinder' or 'Yankee cylinder'. Paper is finally rolled over spools.

Fig. XVIII—4 gives a general view of a papre machine.

Flow-sheet.—The flollowing flow-sheet illustrates the successive stages in the production of paper :

Wood → Debarking → Chipping → Screening → *Digestion → Blow tank → Coarse screening → *Washing → Screening → Bleaching → Washing → Beating → Paper-making → Cutting → Sorting and Packing.

Secondary process :— *Washing → Black liquor storage → Soda recovery → White liquor → *Digestion.

Classification of paper

Paper is classified into two broad categories, paper and paperboard, on the basis of weight per unit area of the sheet. The dividing line is usually a weight of 250 grams per square metre. A number of varieties of paper and paperboard are distinguished. The better-known ones are described below separately under paper and paperboard.

Categories of paper.—Of the several categories, the following 15 kinds of paper are of importance :

(1) *Airmail paper.*—This is used for letters and circulars mailed by air. Light weight is the most significant property. Opacity is also important.

(2) *Art paper.*—This is used for half-tone reproductions of the highest quality. It consists of a base paper made of chemical pulp, to which a surface-coating of mineral matter mixed with adhesive is applied in such a way that the fibres of the body paper do not at all show on the surface.

(3) *Bible paper.*—This is a light-weight, opaque, printing paper used in books, bibles and encyclopaedias, where small bulk is an essential feature. It is generally made from rag pulp, using titanium dioxide as a filler.

(4) *Blotting paper.*—This is the simplest paper from the structural point of view. In its manufacture the main object is to produce an open, absorbent sheet and, therefore, the blocking of the channels should be avoided. The fibres should be clean and of good quality (preferably cotton), and the beating process is restricted to a cutting action. No loading is added in the beater.

(5) *Bond paper.*—This is a grade of writing or printing paper originally used where strength, durability, and permanence are essential requirements, e.g., government bonds, legal documents, etc. Its use has extended into other fields, such as business letter-heads and forms, where strength and permanence are really not so essential. Its special qualities are obtained by the use of a mixture of rag and chemical pulp.

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(6) *Book paper.*—Book papers vary considerably according to the class of book involved. The better grades are usually made from chemical pulp, but for cheaper productions the papers are made largely of mechanical pulp.

(7) *Cigarette paper.*—The requirements of cigarette papers are rather exacting. The paper must have no characteristic smell or taste on burning, and it must be thin but yet opaque, since the appearance of the cigarette suffers it the tobacco shows through the covering to any marked extent. Opacity is secured by the addition of a filler such as calcium carbonate which also gives a good white appearance and helps to promote the uniform burning of the paper. The raw material used in India for cigarette paper is sunn hemp (*Crotalaria juncea*).

(8) *Cover paper.*—This is used for the outside covers of catalogues, pamphlets, booklets, magazines, and other printed matter requiring protection from handling. It is made from chemical pulp in a range of weights and colours. Some of the essential features are folding qualities, permanence of colour' even printing surface, and high resistance to handling and abrasion.

(9) *Drawing paper.*—A good-quality drawing paper must be strong permanent, white and opaque and should take on Indian and writing inks well, accept colour wash without mottle, and withstand the action of India-rubber or an erasing knife. It is made from rag pulp or chemical pulp and is well sized. Opacity is obtained by increasing the thickness as the weight of the sheet is of minor, importance.

(10) *Grease-proof paper.*—The satisfactory permanence of grease-proof papers depends on the extent to which the pores have been closed. This is done by beating the fibres to a much greater extent than is necessary (or desirable) for most other papers, so that the pulp approaches the jelly stage. Papers made from such a pulp have comparatively few inter-connecting pores between the fibres, with the result that the passage of liquids is difficult.

(11) *Imitation art paper.*—This is a paper cheaper than art paper but with a surface similar to that of art paper. It is made by adding a large quantity of mineral loading to the pulp in the beater; it is decidedly inferior to art paper from the point of view of appearance and finish, but is sufficiently smooth to give reasonably good results with fine screen half-tone blocks.

(12) *Kraft paper.*—This is a comparatively coarse paper, particularly noted for its strength, and is used as a wrapper or packaging material. It is made entirely from unbleached pulp produced by the sulphate process. In addition to its use as a wrapping paper, it is also converted into such products as grocer's bags, envelopes, multi-wall sacks, etc.

(13) *Ledger paper.*—This is used for writing purposes, especially for pen and ink-records. It is usually made from a mixture of rag pulp and chemical pulp, and is well sized. As it is subjected to appreciable wear, it requires a relatively high degree of durability and permanence. Significant properties include strength, erasibility, water-and ink-resistance, uniformity of surface and colour, and smoothness. A good surface for ruling is also important.

(14) *Newsprint.*—This is the paper used for newspaper printing. Cheapness is of paramount importance. Permanence is unnecessary, but the printed matter must be clearly legible and half-tone illustrations recognizable. It is made from mechanical pulp containing sufficient (usually about 30 per cent) chemical pulp to give the sheet necessary strength.

(15) *Vegetable parchment.*—This is a paper resembling animal parchment, and is made by passing a sheet prepared from rag or pure chemical pulp through a bath of sulphuric acid and then thoroughly washing and drying it. It is odourless, tasteless and grease-resistant, and has a high wet strength. It is used principally as a wrapper for butter, meat, fish and almost all moist food products and as a speciality for letter-heads, greeting cards, etc.

Categories of paperboard.—Three categories of paperboard, viz., duplex board, strawboard and millboard, are worth mention.

Duplex boards are two-ply boards made from two differert stocks on a cylinder mould machine : generally the top layer is made from good-quality pulp and the bottom layer from waste paper. They are used in the manufacture of packing cartons. The top layer should have a good printing surface, and the board should be stiff and capable, at the same time, of folding neatly without cracking.

Strawboards and *millboards* are cheap paperboards, made on crude paper machines. Strawboards are made from agricultural residues, like wheat straw, rice straw or bagasse, cooked with lime. Millboards are made from waste paper obtained in road sweeping.

Indian Paper Industry

Late in the 18th century, the art of paper-making spread to India from China. The history of modern paper-making in India, however, started about 1830 with the installation by Dr. Carey, a foreign missionary, of the first paper machine in India at Serampore, West Bengal.

In 1867, a paper mill was established in Bally, West Bengal, to work on a commercial scale. This mill took the machinery from Serampore. Raw materials used by this mill were chiefly waste paper and old rags. The Upper India Couper Paper Mills, Lucknow, established in 1882, and the Titaghur Paper Mills, Ltd., Titaghur, West Bengal, established in 1884, were amongst the first mills to use sabai grass as fibrous raw material. The suitability of sabai grass was then established and other mills also came up on this raw material.

In 1912 the Titaghur Paper Mills reconstructed the mill at Titaghur to utilize bamboo. By this time the Forest Research Institute had established the fact that bamboo could be pulped to yield good quality papers. In 1918 Messrs. Andrew Yule and Co. Ltd. set up a mill at Naihati which employed acid pulping for bamboo. By the utilization of bamboo the production of paper immediately shot up. From 27,000 tonnes in 1924-25 the production shot up to 39,600 tonnes in 1930-31, 87,700 tonnes in 1940-41, 107,600 tonnes in 1950-51, 369,400 tonnes in 1960-61 and 520,700 tonnes in 1964. Most of the big mills were based on bamboo as the main raw material. The available supplies of bamboo are almost fully tapped. Keeping in view the inadequacy of bamboo supplies in the context of the expanding needs of paper industry, the Forest Research Institute did intensive work on the utilization of hardwoods. Although several individual species of hardwoods were found suitable, the results could not be put to use by the paper industry as individual species are seldom available in sufficient quantities and in concentrated blocks for economical exploitation. In our forests the hardwoods usually grow in mixture. The Forest Research Institute, therefore, started working on mixed hardwoods. It is now an established fact that utilization of mixed hardwoods for paper is possible. Messrs. Bengal Paper Mills Ltd., Raniganj, and Messrs. Star Paper Mills Ltd., Saharanpur, have started utilizing mixed hardwoods as a regular part of the furnish, and other mills are following suit.

At present there are 56 mills in India making paper and paperboards. The paper mills in different States and their capacity and production, as in 1966, are given in Table XVIII-1.

Table XVIII-1

Paper mills in India and their capacity and production, 1966

Name of mills (by States)	1966	
	Capacity	Production
	Tonnes	Tonnes
Andhra Pradesh		
1. Sirpur Paper Mills Ltd.	40,000	31,821
2. Andhra Pradesh Paper Mills Ltd.	12,000	686
Bihar		
3. Rohtas Industries Ltd.	60,000	43,885
*4. Thakur Paper Mills Ltd.	3,000	Not available
Gujarat		
5. Gujarat Paper Mills Ltd.	6,000	1,806

Name of mills (by States)	1966	
	Capacity	Production
	Tonnes	Tonnes
6. Rohit Pulp & Paper Mills Ltd.	6,600	3,902
7. Jayant Paper Mills Ltd.	5,000	4,246
8. Steadfast Paper Mills	450	212
9. Parekh Paper Mills	1,000	328
*10. Speciality Papers Ltd.	1,440	Not available
Haryana		
11. Shri Gopal Paper Mills Ltd.	40,000	36,038
12. Murari Paper Mills	1,200	309
13. Delhi Pulp Industries	3,000	2,545
14. Rajendra Paper Mills	1,560	1,009
Kerala		
15. Punalur Paper Mills Ltd.	11,640	6,440
16. Gwalior Rayon Silk Mfg. (Wvg.) & Co. Ltd.	2,700	2,023
Madhya Pradesh		
17. Straw Products Ltd.	8,000	6,348
18. Alok Paper Industries	1,200	390
19. Orient Paper Mills Ltd.	65,000	51,544
20. Mandidip Paper Mills Pvt. Ltd.	3,000	928
Maharashtra		
21. Deccan Paper Mills Co. Ltd.	3,600	1,883
22. D. Pudumjee Paper Mills Ltd.	1,800	1,111
23. Paper & Pulp Conversions Ltd.	7,500	6,453
24. Pudumjee Paper Mills Ltd.	3,300	828
25. Ballarpur Paper & Straw Board Mills Ltd.	45,000	44,309
*26. Providence-Paper Mills	510	Not available
27. Premier Paper Mills Ltd.	2,100	1,103
28. Oriental Timber Trading Corporation (P) Ltd.	1,500	1,023
29. Ajanta Paper & General Products Pvt. Ltd.	1,800	828
30. Paper Products Ltd.	4,800	2,488
31. Vidharbha Paper Mills Ltd.	1,500	1,091
32. Bombay Paper Mfg. Co.	900	825
33. Afsons Industrial Corporation (P) Ltd.	2,400	1,041
Mysore		
34. Mysore Paper Mills Ltd.	19,000	17,794
35. West Coast Paper Mills Ltd.	36,000	35,261
36. South India Paper Mills (P) Ltd.	3,000	2,402
37. Mandya National Paper Mills Ltd.	10,800	2,151
38. Senapathy Whitely (P) Ltd.	840	472
Orissa		
39. Orient Paper Mills Mills Ltd.	70,000	64,589
40. Straw Products Ltd. J. K Paper Mills)	20,000	18,471

Name of mills (by States)	1966 Capacity	1966 Production
Tamil Nadu		
41. Seshasayee Paper & Boards Ltd.	20,000	20,628
42. Sun Paper Mills Co. Ltd.	3,000	2,079
43. Amravathi Srivenkatesa Paper Mills (P) Ltd.	3,000	1,213
Uttar Pradesh		
44. Star Paper Mills Ltd.	30,000	28,083
45. Upper India Couper Paper Mills Co. Ltd.	4,200	1,782
West Bengal		
46. Titaghur Paper Mills Ltd.	66,000	64,698
47. India Paper Pulp Co. Ltd.	17,500	14,934
48. Bengal Paper Mill Co. Ltd.	36,000	36,658
49. Tribeni Tissues Pvt. Ltd.	6,000	5,787
50. Western India Match Co. Ltd.	6,000	4,389
51. Shree Gopinath Paper Mills	1,080	79
52. Eastend Paper Industries Ltd.	3,000	3,180
53. Priti Paper Board Mills (P) Ltd.	1,800	748
*54. P. Ghosh & Co.	1,500	Not available
55. Snow White Food Products Co. Ltd.	3,000	2,684
TOTAL	711,220	585,051

*Production in these mills, though not separately available, is included in the total.

There is only one newsprint mill in the country, namely the National Newsprint and Paper Mills, Ltd., Nepanagar, Madhya Pradesh. This mill produces at present 30,000 tonnes per year of newsprint from a furnish which consists of 60 per cent salai mechanical pulp and 40 per cent bamboo chemical pulp. During 1966, 91,550 tonnes of newsprint had to be imported to meet the country's requirements. In adition there are a number of small strawboard and millboard plants which made 70,418 tonnes of this cheap material in 1966.

Paper is one of the basic needs of modern life and the amount of paper consumed in a country is sometimes taken as an index of the state of its development. After the country became independent the consumption of paper and paperboard has steadily increased in India as a result of rise in the living standard of the people. But, even so, the present per-capita consumption of paper and paperboard in the country is one of the lowest in the world as can be seen from the figures given in Table XVIII-2.

TABLE XVIII-2

Consumption of paper and paperboard in some countries in 1964

Country	Population (Thousands)	Per-capita consumption (kg)
U.S.A.	192,119	217.0
Sweden	7,666	140.6
Canada	19,916	138.3
U.K.	54,066	119.7
Denmark	4,680	111.6
Japan	98,000	73.9
France	48,750	71.9
Philippines	30,000	6.3
China	700,000	4.1
India	465,000	1.45
Mali	4,408	0.065

The consrmption of paper and paperboard during the last few years has, however, been steadily increasing. The consumption has increased by over 270 per cent as it can be seen in Table XVIII-3.

TABLE XVIII-3

Progress in consumption (production and imports) of paper, paperboards, etc. in India.

(*In* 1,000 *tonnes*)

Year	Paper and paperboard	Newsprint	Strawboard and millboard	Total
1951—52	168.0	50.0	24.0	242.0
1952—53	176.0	54.0	26.0	256.0
1953—54	179.0	70.0	28.0	277.0
1954—55	207.0	79.0	33.0	319.0
1955—56	237.0	78.3	36.0	351.3
1956—57	242.0	76.4	42.0	360.4
1957—58	260.5	77.9	45.0	383.4
1958—59	276.0	79.0	45.0	400.4
1959—60	330.0	96.0	51.0	477.9
1960—61	366.0	98.0	60.0	524.4
1961—62	389.0	118.9	60.0	597.9
1962—63	411.0	125.8	66.0	602.8
1963—64 (Estimated)	493.0	100.0	68.0	661.0

RAYON

For thousands of years man has depended directly on natural fibres for the production of textiles. The relative importance of the natural fibres like cotton, wool and silk can be seen from the following figures of world production in 1957 :

Cotton	8.0	million tonnes
Wool	1.9	million tonnes
Silk	0.026	million tonnes

However, as early as 1664, Robert Hooke thought man himself should be able to prepare a solution similar to what the silkworm makes and then draw the solution out in the form of a thread by some mechanical means. Two hundred years later Hooke's dream was to come true. A French chemist, Count Hilaire de Bernigaud de Chardonet, produced the first artificial fibre in 1884. He dissolved nitro-cellulose in a mixture of ether and alcohol and forced the solution through a group of tiny holes in a spinnerette. The solution was transformed by evaporation of the solvent into solid filaments. Other methods of production of artificial fibres were soon developed and today the fibre produced by the viscose process is the most important commercial artificial fibre.

A description of the viscose-rayon process is given below :

Viscose-rayon process

Steeping.—The sheets of pulp are stacked on edge between perforated steel plates in tanks full of caustic soda solution of 17-18 per cent concentration and the pulp is allowed to soak for about two hours. By this treatment hemi-celluloses, which are soluble in caustic soda, are leached out, whereas cellulose is insoluble in this concentration of caustic soda. About 15 kg of caustic is used per kg of pulp in this steeping operation. When the batch is ready to be discharged from the steeping tank, called the 'steeping press', as the latter is equipped with a hydraulic ram, a valve is opened and the free caustic liquor allowed to drain off; then the hydraulic ram is set in motion, causing the head of the ram to squeeze and compress the pulp sheet, so as to make it give up part of the caustic liquor it had absorbed, until its weight is brought down to approximately three times its original dry weight. This caustic-treated cellulose is called alkali cellulose.

Shredding.—The alkali cellulose sheets are reduced in size to a mass of fibres resembling bread crumbs. This is done in a shredder where large press sheets are reduced to fine crumbs. This is not a grinding process but one of shredding, whereby cellulose fibres are loosened and fluffed but are permitted to retain their length. This also gives an intimate mixing or blending, thus equalizing any lack of uniformity in the caustic content. The temperature is kept around 18°—20°C for about one to three hours.

Ageing.—The shredded alkali cellulose from the shredder is discharged in cans with loosely-fitted covers. These cans are kept in a temperature-controlled ageing room. Here for many hours the cellulose rests while its molecular structure undergoes a change.

Xanthation.—This is the conversion of the alkali cellulose into cellulose xanthate by treating it with carbon disulphide for two or three hours at 20°—35°C. The machine in which it is done is known as a 'churn'.

Dissolving.—The cellulose xanthate is dissolved in dilute caustic soda solution in a mixture tank. The cellulose xanthate slowly dissolves and the resultant product is viscose, a complex chemical compound containing the cellulose in a form from which rayon yarn can be spun.

Filtration.—Viscose is filtered to remove undissolved particles of cellulose and foreign matter, which must be carefully removed before it goes to the spinning room.

Ripening.—As initially prepared, viscose is relatively difficult to coagulate and, hence, is not suitable for most industrial operations. To make it fit for applications such as spinning and casting, the viscose is transferred to large tanks in another constant-temperature room where it is stored under controlled conditions of time and temperature to permit ripening.

Spinning.—This is the conversion of viscose into rayon filaments and the major step in the whole process. Here are involved two elements : the viscose and the spinning bath in which it is coagulated. The viscose is brought to the spinnerette or nozzle by a little pump built to deliver it with great accuracy as to pressure and quantity per minute. Before entering the spinnerette, the viscose passes once more through a small filter, known as the 'candle filter', because any tiny particles of solid matter in viscose will plug one or more of the minute holes in the spinnerette and an entrained air bubble will break the continuity of the filament. The spinning bath in which the viscose is extruded is composed of warm watter (around 40°—45°C) containing roughly 8-10 per cent sulphuric acid, 13½-21 per cent sodium sulphate, about 1 per cent zinc sulphate and about 4—10 per cent of corn sugar or glucose. When the viscose, composed of about 7 per cent cellulose and 6½ per cent caustic soda, meets this

chemical solution in the trough of the spinning machine, it coagulates. The neutralization of the caustic soda in the viscose by the acid in the bath results in the breakdown of the cellulose xanthate and the precipitation of regenerated cellı lose.

To start the thread on its way, the operator siezes the emerging filaments, and leads then first to a hook and then to a centrifugal pot. The rotation of this pot causes the group of filaments to be twisted into a unit thread of the desired twist and the thread is wound on it.

Washing.—The yarn is then washed, dried and desulphurized. The yarn as it comes from the spinning machine is still saturated with the spin-bath liquor. This is rinsed off with water and the yarn passed through heated dryers. The sulphur or sulphur compounds clinging to the yarn are removed by passing the yarn in an alkaline sulphide solution which dissolves sulphur.

Bleaching.—The yarn has a dull, yellowish colour. To obtain pure, white yarn, a final treatment of bleaching with dilute hypochlorite solution is resorted to. The bleached yarn is washed and again dried.

Rayon-grade pulp

In 1903 the Bohnodalen Mill in Norway began to deliver bleached sulphite pulp for textile purposes to England. The viscose industry expanded rapidly, 200,000 tonnes having been produced in 1930 and 2,000,000 tonnes in 1950. The viscose process is used in the manufacture not only of textile rayon but also of transparent film (cellophane) and high-tenacity yarns used in the making of pneumatic tyres. The importance of the viscose process for the pulp industry can be seen from the following table which gives the various applications of *dissolving pulps*, as pulps used for chemical conversion are called.

TABLE XVIII-4

Approximate world consumption of cellulose in 1960 for chemical conversion under different processes.

(*In* 1,000 *tonnes*)

Process	Consumption		
	Textile fibre purposes	Non-fibre purposes	Total
Viscose	2.40	0.40	2.80
Acetate	0.16	0.04	0.20
Nitrate		0.07	0.07
Cuprammonium	0.06	0.01	0.07
Etherifications	—	0.07	0.07
Total	2.62	0.59	3.21

However, the proportion of pulp required for chemical conversion is only a small proportion of the total pulp production of 63 million tonnes, the major fraction being used for paper production where the pulp fibres are mechanically modified to give a coherent sheet. The specifications for viscose-rayon-grade pulp are more stringent than for paper pulp.

Directly related to the viscose process is the *alpha-cellulose determination*. The pulp sample is treated with 17.5 per cent sodium hydroxide solution, which is added at intervals and the pulp repeatedly macerated with a stirring rod. After a defined swelling period, an equivalent volume of water is added, the pulp suspension filtered and the filter cake washed with water, acetic acid and water again before drying and weighing. This insoluble fraction is called the *alpha-cellulose*. The combined filtrate and washings are acidified with sulphuric acid and the precipitate, *beta-cellulose, allowed* to settle, leaving *the gamma-cellulose* in solution. The former can be determined volumetrically or gravimetrically, but the latter is always be determined volumetrically. As the quality of dissolving pulps is closely related to some of its impurities, even routine control involves the determination of *ash content* and *extractives* or *resin*) content. The main specifications for the different types of viscose-rayongrade pulps are given below :

	Cellophane	*Textile*	*Tyre cord*
Alpha-cellulose	87—91	89—92	94—96
Beta-cellulose	5—7	3—5	2—3
Gamma-cellulose	3—5	3—6	1.5—3.5
Ash	0.05—0.13	0.04—0.13	0.04—0.08
Ether solubility	0.1—0.3	0.1—0.3	0.05—0.15
Degree of polymerization	100—200	250—700	250—700

Until about 1940, only the sulphite process could be used for the production of dissolving pulps. Two main factors have made the sulphite process less capable of competition, namely, its sensitivity to the wood raw material and the difficulty of recovering the cooking chemicals and utilizing the waste products which amount to half the wood substance. The sulphite process can use only softwoods free from certain extractives of phenolic character and a few hardwoods. Thus spruce (*Picea* spp.) and fir (*Abies* spp.) were the main raw materials for rayon pulp production.

However, during World War II, the pre-hydrolysis sulphate process was developed in Germany. This process can be used on most wood species. It is carried out with water, steam or mineral acid in the first stage and this treatment is followed with a conventional sulphate cook. The changes in pH during a multi-stage cook are appreciable and require high corrosion-resistance in construction materials. During the pre-hydrolysis stage, a considerable part of the hemi-celluloses and a little cellulose are hydrolysed to shorter chains, part of which dissolve in the cooking liquor together with a limited fraction of acid-soluble lignin. In the sulphate cook, the remaining hemi-celluloses are more easily dissolved and the main delignification reaction will also take place, as well as the normal or somewhat increased alkaline degradation of cellulose. The net result of the two stages is therefore a high-alpha pulp of reduced yield.

Indian rayon industry.—The following mills produce(a)viscose-rayon yarn, (b) viscose staple fibre (c) cellulose film, and (d) viscose tyre cord :

		Installed capacity tonnes per year
(a) *Viscose-rayon yarn*		
1. Messrs. National Rayon Corpn. Ltd., Bombay		9,000
2. „ Travancore Rayons, Rayonpuram, Kerala		3,500
3. „ Century Rayons, Bombay		9,000
4. „ J. K. Rayons, Kanpur		3,000
5. „ Kesoram Rayons, Calcutta		4,000
6. „ South India Viscose Ltd., Coimbatore		4,000
7. „ Baroda Rayon Corpn. Ltd., Surat		3,000
8. „ Indian Rayon Corpn. Ltd., Bombay		2,000
	Total	37,500
(b) *Viscose staple fibre*		
1. Messrs. Gwalior Rayons Silk Mfg. Co., Nagda		40,000
2. „ South India Viscose, Coimbatore		4,000
	Total	44,000
(c) *Cellulose film*		
1. Messrs. Travancore Rayons, Rayonpuram, Kerala		4,000
2. „ Kesoram Rayons, Calcutta		2,000
	Total	6,000

(d) *Viscose tyre cord*

1.	Messrs. National Rayons Bombay		4,000
2.	„ Century Rayons, Bombay		4,000
3.	„ Shriram Rayons, Kotah		4,000
		Total	12,000
		Grand Total	99,5C0

The requirement of rayon-grade pulp is about 1.05 tonnes per tonne of textile yarn and about 1.1 tonnes per tonne of tyre cord. As, however, the production will be slightly lower than the installed capacity, the requirement of rayon-grade pulp at present can be taken roughly as 100,000 tonnes. This is expected to rise to about 200,000 tonnes by 1970, 450,000 tonnes by 1975, and 600,000 tonnes by 1980.

Following is the list of raw materials tested and found suitable for rayon-grade pulp at the Forest Research Institute, Dehra Dun :

Bamboo

1. *Bambusa arundinacea*
2. *Dendrocalamus strictus*
3. *Melocanna bambusoides*

Hardwoods

4. *Acacia decurrens*
5. *Acacia mollissima*
6. *Boswellia serrata*
7. *Broussonetia papyrifera*
8. *Eucalyptus globulus*
9. *Eucalyptus grandis*
10. *Eucalyptus* (Mysore hybrid)
11. *Ochroma lagopus*
12. Mixture of hardwoods as used by Bengal Paper Mills, Raniganj

Reeds

13. *Arundo donax*
14. *Ochlandra travancorica*

Conifers

15. *Abies pindrow*
16. *Picea morinda*

REFERENCES

Anon 1951 The Dictionary of Paper ; American Paper and Pulp Association, New York.

Anon 1964 Souvenir for International Seminar on Raw materials for more Paper; Indian Pulp and Paper Technical Associaton, Delhi.

Bhargava, M. P. 1942 Bamboo for pulp and paper manufacture, Parts I-III ; *Indian For. Bull.* (N.S.), No. 129, Utilization; Manager of Publication, Delhi.

Bhargava, M. P. & Nayar, A.N. 1941 Manufacture of Insulation and Pressed Boards, Wrapping-papers and Straw Boards from Bagasse; Manager of Publications, Delhi.

Bhargava, M. P., Kasbekar, G. S. & Bhargava, R.P. 1949 Utilization of Bagasse for wrapping and bag paper manufacture; *Indian For. Bull.* (N.S.), No. 148, Cellulose and Paper; Manager of Publications, Delhi.

Bhat, R. V., Virmani, K. C. & Jaspal, N.S. 1951 Indigenous cellulosic raw materials for the production of pulp, paper and board, Parts I & II; *Indian For. Leafl.* Nos. 123 & 124, Cellulose and Paper; Manager of Publications, Delhi.

Bhat, R. V., Guha, S. R. D., Singh, M. M. *et al* 1951 1958 Indigenous cellulosic raw materials for the production of pulp, paper and Parts III —XXX; *Indian For Bull.* (N.S.) Nos. 152, 153, 155—161, 163-165, 163-165, 173, 174, 176, 180-183, 186, 188, 190, 195-197, 204-206, Cellulose and Paper; Manager of Publications, Delhi.

Bhat, R. V. & Virmani, K.C. 1957 Newsprint from blue gum (*E. globulus.* Labill.) and Wattle wood (*Acacia decurrens* Willd.); *Indian For. Bull.* (N.S.); No. 217, Cellulose and Paper; Manager of Publications, Delhi.

Calkin, J. B. 1957 Modern Pulp and Paper Making, III Edition; Reinhold Publishing Corporation, New York.

Casey, J.P. 1960 Pulp and Paper, Chemistry and Chemical Technology, IInd Edition, Vols I & 2; Interscience Publishers, New York.

F. A. C. 1952 Tropical Woods and Agricultural Residues as Sources of Pulp; F.A.O. Forestry & Forest Products Studies No 3; F.A.O. Rome.

F.A.O 1954 World Pulp and Paper Resources and Prospects; F.A.O., New York.

Grant, J. 1958 Cellulose Pulp and Allied Products; Leonard Hill Limited, London.

Hunter, D. 1947 Papermaking, 2nd Edition ; Pleiades Books, London.

Leeming J. 1950 Rayon : the first Man-made Fibre; Chemical Publishing Co., Inc., New York.

Ott E. Spurlin, H. M. & Grafflin, M. W. 1954 Cellulose and Cellulose Derivatives, 2nd Edition; Interscience Publishers, Inc., New York.

Podder, V. 1960 Guide to Manufacture of Paper on Small Scale; Rohtas Industries, Dalmianagar.

Stamm, A. J. & Harris, E. E. 1953 Chemical Processing of Wood; Chemical Publishing Co. Inc., New York.

Stephenson J. N. 1950, 51, 1953, 55 Pulp and Paper Manufacture Vols. ,1,2,3 & 4; McGraw-Hill Book Company, Inc. New York.

CHAPTER XIX

DESTRUCTIVE DISTILLATION OF WOOD

When wood is heated to ignition temperature in the presence of oxygen, it burns spontaneously with the generation of heat and is converted into carbon dioxide and water vapour, leaving behind only a little mineral ash. If heated in the absence of oxygen, however, it breaks down into many new chemicals such as carbon-monoxide gas, acetic acid, wood-alcohol, tar, and charcoal and other less important materials; this is called 'destructive distillation of wood', or 'wood distillation' for short.

The destructive distillation of wood is a long-established industry in many timbered regions of the world, and is next in importance among chemical industries only to the distructive distillation of coal. It has been practised for generations in Europe and America, primarily for the production of charcoal, acetic acid or methyl alcohol (methanol) and secondarily for wood tar, the chief factors favouring it as a permanent industry being its ability to use thinnings, lops and tops, rejects, and waste wood. Both hardwoods and softwoods can be used in the distillation, but the processes are distinct as the products derived differ in character. Certain deciduous hardwoods have been found to be most suitable for destructive distillation. The hardwood distillation industry in the U.S.A. alone produces 30 million bushels (about 270,000 tonnes) of charcoal, 30, 000 tonnes of acetic acid and 5 million gallons (about 19,000 cu m) of methanol ; besides, more than sixty other chemical compounds have been isolated, but these are not of commercial importance at present. The industry has, however, not gained appreciable ground in India, due primarily to economic reasons.

HARDWOOD DISTILLATION

Development of the industry.—The ancient method of charcoal production, for use chiefly as fuel and for reduction of metals was to pile wood in a heap, cover this with turf or earth to prevent entrance of air, and set fire to the pile. The same crude method is, in fact, in use today in many parts of the less-developed countries in Asia, Africa and South America. The process is designed to effect incomplete combustion of wood, without any attempt to retrieve the escaping gases. By the eighteenth century, it was discovered that by heating wood in a closed chamber the pyroligneous acid could be condensed and saved. In the large steel ovens in use today, the process remains the same, viz., heating wood with limited access to oxygen (air); only the technology and efficiency for complete utilization have been vastly improved.

Rapid development in the technology of destructive distillation of wood took place during the last half-a-century or more, and it has become an established industry in many lands. Vigorous research both in technique and technology of the process led to the improvement of method and machinery to the highest point of efficiency. The present-day process of destructive distillation is not only confined to main wood but also to waste wood, particularly small wood such as chips, shavings and sawdust, so that these materials are profitably used. India, with her large natural resources of raw material to draw upon, has a considerable scope for establishing the wood distillation industry and falling in line with countries like the U.S.A., Australia, and Canada.

In modern practice, the carbonizing vessel for hardwoods is generally a cylindrical wrought-iron retort built into brickwork in a horizontal position. This retort is heated by a fire below, but the naked flame is not allowed to impinge directly on the retort, which is heated only by the hot furnace gases, this result being obtained by utilizing iron or brick shields or arches. The batteries of retorts are set up in rows and the outlet pipe of each retort is connected with a worm condenser made of copper and cooled externally by means of running water. On the application of heat to the retort, the substance of the wood is charred, which results in the volatile products being given off. Those volatile products as are condensable are liquefied again in the condenser and are collected in suitable receivers.

Destructive distillation usually begins at 250°C and is finished at about 350°C, when practically all of the acetic acid, wood-alcohol, and wood tar have been evolved. The yield of the important products in wood distillation is somewhat as follows :

Charcoal	Up to 33% from dry wood, about 28% from wood with 20% moisture and 17% from wood with 50% moisture (as at Bhadravati Iron and Steel Works).
Wood tar	7-11%
Acetic acid	4.5-5%
Methyl alcohol	2%

In the early days of crude wood carbonization, charcoal was the principal product. With the development of modern methods of wood distillation and the decline in the use of charcoal in the iron industry, the distillates became the principal times and the charcoal the by-product in the advanced countries. The distillates have lately lost ground to the more efficiently produced synthetic chemicals, and charcoal has again emerged as the principal product. It has still many industrial applications, but its importance in advanced countries like the U.S.A. lies in its having emerged as a speciality item for outdoor cooking in addition to its occasional use for indoor cooking as well.

This is the general outline of wood distillation, but the process will be made clearer from the account given below of a wood distillation plant at Bhadravati in Mysore State. This plant, probably the largest of its kind in the East, is one of the commercial wood-distillation plants in India.

Hardwood distillation in Bhadravati Iron and Steel Works.—The first step is the preparation of the wood used for distillation. This is an important matter as the cost of wood is more than 50 per cent of the cost of manufacture. To suit the cars in which the wood is loaded and the retorts in which carbonization takes place, the wood is prepared in the form of billets of length 1.3 m and girths ranging between 7.5 cm and 15 cm. The species used are principally axlewood (*Anogeissus latifolia*), amaltas (*Cassia fistula*), dhaman (*Grewia* spp.), benteak (*Lagerstroemia lanceolata*), lendi (*L. parviflora*), bijasal (*Pterocarpus marsupium*), jalari (*Shorea talura*), irul (*Xylia xylocarpa*), etc.

Wood, when freshly cut, contains a high percentage of moisture and is not fit for distillation in this state. It is therefore necessary to reduce its moisutre content before it is used, and this is done by stacking and exposing it to the drying influence of the atmosphere. It takes 6 to 12 months to reduce the moisture to the required limit in this way. Another method, which, however, is not followed at Bhadravati, is to keep the wood in a specially constructed chamber and circulating hot gases through it.

There are 10 retorts at this plant, arranged in 5 pairs. Normally 8 retorts are in operation, two being down for repairs, cleaning, etc. Each of the retorts holds 4 carloads of wood weighing from 18 to 20 tonnes. As soon as the cars have been loaded into the retort and the retort closed and made airtight, the fires are lit in the furnaces below and distillation begins.

As the temperature rises, most of the water in the wood is driven off in the form of vapour and the wood gradually begins to decompose and give of traces of acetic acid. When the temperature of the vapour reaches 200°C, traces of tar appear and the decomposition becomes more rapid, with a corresponding increase in the volume of the vapour given off. At this stage, known as the exothermic stage, considerable heat is released by the decomposition of the wood itself. Hence, if the external supply of heat is not controlled, the temperature of the vapours rises too rapidly and the reaction gets out of control, resulting in serious loss of products and sometimes causing explosions. Hence, in practice this stage is carefully watched for, and the firing of the retort is so regulated that there is a very gentle rise of temperature between the range of 230° and 280°C. This range is covered by at least half the period of the distillation, viz., 12 hours. When the reaction shows signs of abating, as can be judged from the fall in the flow of liquor, the temperature is further raised to 330° or 360°C to complete the reaction and improve the quality of charcoal.

A portion of the vapour evolved during the decomposition of the wood is non-condensable and issues from the condensers as gas. This gas is burnt under the retorts as fuel.

Carbonization of each charge takes 24–36 hours. On its completion, the cars of glowing charcoal are pushed into an airtight steel cooling-chamber similar to retorts and allowed to cool for 24 hours

in primary coolers with water spray on top and for 24 hours in secondary coolers. The charcoal is then allowed to cool for 24 hours more in an open shed before being issued for use in the blast furnaces of the iron works.

The average amount of wood carbonized per day is about 100 tonnes on 36-hour cycles, which yields about 30 tonnes of charcoal and 45,000 to 50,000 litres (10,000 to 11,000 gallons) of pyroligneous liquor. On a 24-hour cycle the production is increased by 50 per cent.

This pyroligneous liquor contains about 3 per cent of tar in suspension and an equal amount in solution, 4 to 5 per cent of acetic acid and about 3 per cent of alcohol, the remaining about 85 per cent consisting mostly of water and impurities.

The main product from the carbonization of hardwoods is charcoal with calorific values ranging from 6,200 to 7,500 calories. Charcoal is used as a domestic fuel, in the blast furnace for smelting ores, and for the manufacture of ferrosilicon, calcium carbide, carbon tetrachloride, carbon disulphide, etc.

In the *still* house, the pyroligneous liquor is first pumped into wooden settling tanks where it is allowed to stand for some time. The suspended tar then settles to the bottom and is drawn off. The tar so obtained is termed 'settled tar' and is distilled in the tar plant to give oils and pitch.

The remaining supernatant liquid is then distilled in copper vacuum evaporators to get rid of the tar in solution. The tar so obtained is known as 'dissolved tar', and is not so valuable as the settled tar. It is free from acid and is burnt under the boilers in the plant.

The distillate from the copper evaporators is then neutralized with slaked lime to convert the acetic acid into acetate of lime. The neutralized liquor is then subjected to fractional distillation to separate the alcohol and leave behind a dilute solution of lime acetate. This solution is evaporated to dryness to give solid lime acetate. This is known commercially as 'grey acetate of lime' and is 80 per cent pure.

In the Western countries, competition from synthetic acetic acid and synthetic methanol led to the abandonment of the acetate-of-lime method of acetic acid production described above and the development of methods of directly recovering acetic acid from the pyroligneous liquor. The Direct-Acetic-Acid Recovery Process was first invented by Suida, an Austrian professor. In this process, the acetic acid is directly extracted from the pyroligneous liquor by using ethyl acetate, and the remaining liquid is subjected to fractional distillation to recover the other by-products like methyl alcohol, acetone, glacial acetic acid, and dissolved tar. The Bhadravati wood distillation unit introduced the Direct-Acetic-Acid Recovery Plant in 1951, supplanting the acetate-of-lime method of producing acetic acid.

The alcohol obatained as described above is known as crude wood-alcohol or crude methanol. It contains about 75 per cent of pure alcohol, about 15 per cent of acetone and about 10 per cent of water and oils. It is refined in the alcohol refinery to give pure commercial methanol and a product known as methyl acetone.

The settled tar, obtained from the settling tanks into which the pyroligneous acid was first pumped, is treated in the tar plant. The tar is heated in steel stills provided with copper condensers. The first fraction contains acid liquor held in solution by the tar and oils lighter than water. The second fraction is known as heavy oil. The pitch is left behind in the still in a molten condition and is then run into coolers and allowed to cool.

The light oil is used with pitch to make a black paint, while the heavy oil is redistilled and supplied to the creosoting plant as wood-preserving oil or creosote oil. Mixed with fuel oil it was once used for treating sleepers for the Mysore Railway, but its use for this purpose has now been abandoned.

Laboratory experiments have shown that this creosote derived from wood is as toxic, if not more so, than creosote derived from coal. Experience has shown, however, that some of the tar acids are leached out by moisture and that the toxic effect of the creosote is thereby greatly reduced when sleeper treated with it are exposed to moist atmospheric conditions.

A disinfectant known as 'Kerso' is also made in the tar plant. This is made from the oil known as neutral oil obtained during the separation of the crude alcohol from the pyroligneous liquor. This oil is rich in phenols and is separated by distillation and made into a disinfectant.

Acetate of lime, which was produced in the old process, was mainly used for the manufacture of acetone for making cordite, in the manufacture of acetic acid for use in the textile and rubber industries, and in the manufacture of cellulose lacquers and artificial silk. Acetic acid, which is directly recovered in the new process, is widely used in chemical industries.

The methyl acetone as noted above, is used as a solvent in various industries, while methanol is used in the manufacture of formaldehyde or formalin and in the dye industry. It is also used in the manufacture of paints, varnishes, and polishes.

A flow sheet showing the various products obtained by the destructive distillation of wood as now being carried out at Bhadravati under the Direct-Acetic-Acid-Recovery Process is reproduced on the following page by courtesy of the Mysore Iron & Steel Ltd., Bhadravati, and this will no doubt help to make the method of production of the various products more clear.

Principal products

The principal products of destructive distillation and their uses may be briefly summarized :

(i) *Gas.*—This has a low heating value as it is admixed with carbon dioxide. It is used as producer gas for the last 30 years.

(ii) *Wood-alcohol (Methanol).*—This is mainly used in the manufacture of formaldehyde, the well-known fungicide and disinfectant and raw material, along with phenol, in the manufacture of synthetic resins, plastics, and glues, and in the coal-tar dye and celluloid industries. It is also used as a solvent in shellac varnishes and lacquers and in the manufacture of dry-cleaning agents, proxylin products, paints, textile finishing agents, etc. It is also extensively used as an anti-freeze.

(iii) *Acetic acid.*—This is used in making inorganic acetates (lead, copper, iron, and sodium), white lead pigments, cellulose acetate fibre, cine and photographic films, lacquers, plastics, methyl, ethyl and amyl acetate solvents, perfumes, etc. It is also used for coagulating plantation-rubber latex and as a mordant in textile dyeing.

(iv) *Acetone.*—This occurs along with wood-alcohol from which it is difficult to separate it. It is largely used as a solvent, especially for cellulose lacquers and films. It is also used in the manufacture of explosives such as 'cordite'.

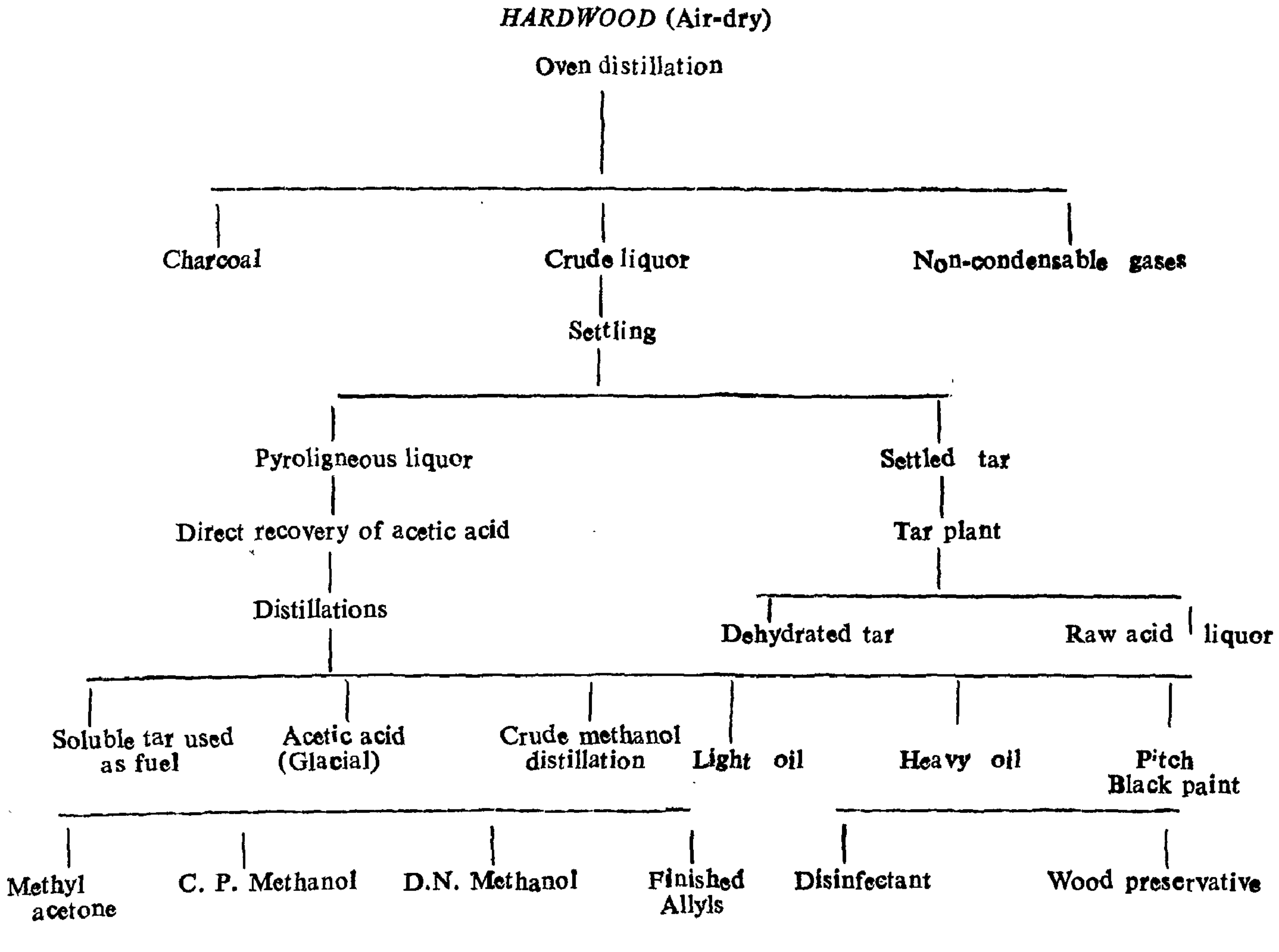
(v) *Methvl-acetone.*—This is a mixture of wood-alcohol, acentone, and methyl acetate, obtained in the refining of the crude wood-alcohol. It is a remarkable solvent and is used for 'denaturing' ethyl alcohol.

(vi) *Tar-oil and pitch.*—Products of tar-oil are used for floatation oils, solvent oils, oils for paints and stains, disinfectants, rubber-softening compounds, wood-creosote preservatives, etc.

(vii) *Charcoal.*—This is chiefly used as domestic fuel. It is also used in blast furnaces, as a reducing agent in metallurgy where its low ash content and the absence of phosphorus and sulphur are important considerations and in the manufacture of explosives, chemical such as carbon bisulphide and sodium cyanide, metal case hardening compounds, etc. Special kinds of charcoal are used in gas masks. *Activated charcoal* is used for removing bad odours, tastes and colours from foods, medicines, etc., and, to some extent, for water purification.

Scope of distillation in India.—India has in her vast forests copious supplies of hardwoods, and wood-distillation plants set up in various regions of the country should prove successful. The paucity of any large-scale demand for charcoal (apart from the case of the Bhadravati Steel Works), the light weight of the charcoal and the consequent uneconomic transport costs, and the absence of established markets for the by-products of wood distillation have made the destructive distillation of wood unfeasible in the past. These factors may not operate to the same extent under present-day conditions , particularly in view of the development of cheaper methods of directly recovering acetic acid from the pyroligneous liquor, and the feasibility of using portable wood-distillation plants deserves active consideration. In Western Europe and North America, synthetic or fermentation methods of producing methanol, acetic acid and acetone have narrowed the market for wood-distillation products derived from pyroligneous acid, but hardwood distillation, integrated with sawmill operation, permits the use of wastes for production of charcoal. In India there is bound to be scope for a considerable

Products Flow Sheet (revised) for Destructive Distillation of Hardwoods in the Mysore Iron & Steel Limited, Bhadravati (Mysore State).



time in terms of demand both of charcoal and of the by-products, for expanding wood-distillation industry on a large scale.

Softwood Distillation

The destructive distillation of softwoods is broadly similar to that of hardwoods, but differences arise in the products and in the methods of refining them. The products recovered are, chiefly, charcoal, turpentine, pine oil, dipentene, pine tar, tar-oils and pitch. The pyroligneous liquor contains such small amounts of alcohol and acetic acid that no attempt is made to recover them. Only the oily fractions of the distillate yield valuable products.

The destructive distillation of softwoods is not being practised in India as a regular Industry. Chir tar, which at one time was produced on a substantial scale, and deodar tar-oil which is produced locally on a small scale, are briefly dealt with below.

Chir tar.—From the old stumps and roots, and to a lesser extent from the boles and branches, of felled chir (*Pinus roxburghii*) trees, a highly resinous wood, locally known as *chilka*, is obtained. By subjecting this *chilka* to a form of crude destructive distillation in an improvised retort a product known as 'chir tar' is obtained. A profitable industry in this product sprang up during the First World War, when it was found that this tar was a fair substitute for imported Stockholm tar (used in the jute mills of Calcutta for tarring ropes, etc.), imports of which were at that time rendered difficult on account of the war. No less than 544 quintals (1,458 maunds) of chir tar were produced in the Kumaon

hills in 1919-20, but after that the market began to disappear, and production had finally to cease altogether, as the result of a return to normal conditions of trade in Stockholm tar.

Attempts have been made at various times to find another market for chir tar, but it was not till 1929 that proposals were put forward to utilize the tar as a local road-surfacing material to replace proprietary compositions in use. Experiments showed that chir tar was unsuitable for the purpose in a crude state. As a result of investigations at the Forest Research Institute, Dehra Dun, a product was evolved from chir tar and was given the name of 'Pintar', and it was thought that this might prove successful as a road-surfacing material. Practical tests on a streatch of the Bareilly-Almora road showed, however, that this was not the caes : 'Pintar' lacked the necessary penetration and also broke up badly as it was too brittle. Further, the 'Pintar', as used, did not compare favourably in price with other road compositions.

The redistillation of 'Pintar' yields such products as Stockholm tar, pine oil, and wood creosote, but, in the absence of any chir-tar distillation, this is for the present only of academic interest.

Deodar tar-oil.—By the destructive distillation of the wood of *Cedrus deodara*, a thick tar-like oil is obtained which is used for rubbing on the inflated skins (*sarnai*) commonly used in India for crossing rivers and as a remedy for ulcers and eruptions, manage in horses, and sore feet in cattle. It is also used to some extent for cremations. This tar is locally prepared and is generally procurable in bazaars adjacent to forests.

REFERENCES

Anon — 1965 — Letter No. WMS/G/10010 D/29.12.64 from Mysore Iron & Steel Ltd. Bhadravati.

Panshin, A.J., Harrar, E.S., Bethel, J.S. & Baker, W.J. — 1962 — Forest Products; Mc-Graw-Hill Book Company, New York.

CHAPTER XX

SACCHARIFICATION OF WOOD

Introduction

Saccharification of wood is the process by which carbohydrates in wood can be converted into simple sugars by chemical treatment. The carbohydrates concerned are mainly cellulose and hemi-celluloses, but the small amounts of mono-, di- and polysaccharides present in the cell fluid are also affected. Wood of most species contains about 70 per cent carbohydrates, of which cellulose contributes to 50 per cent and hemi-celluloses to about 20 per cent. Wood, therefore, constitutes one of the most important potential sources of carbohydrates for conversion into sugar.

The conversion into sugars, which can also be termed the 'hydrolysis of wood', is accomplished by treating wood (usually sawdust, shavings, chips, and other waste materials) with strong acids at room temperature, or with dilute acids at elevated temperature. During this process, cellulose undergoes conversion into glucose, while the hemi-cellulose fractions and the cell-content carbohydrates give rise to a mixture of glucose and other sugars and sugar derivatives. Amongst the other sugars found are galactose, mannose, arabinose and xylose, and, in some cases, fructose also. The relative proportion of these sugars varies from species to species. The resulting solution of mixed sugars can be evaporated to molasses, used to grow yeast, crystallized to glucose sugar, fermented to ethyl alcohol and glycerol, or used to produce furfural as well as a variety of alcohols and acids.

Probably no other chemical process has had such a chequered history as that of the saccharification of wood. Even in the early days of organic chemistry, scientists were confronted with the fact that as much as two-thirds of most cellulosic wastes are carbohydrates, and interested themselves in the possibility of converting the carbohydrate content of wood into sugars, etc. Braconnot discovered in 1819 that cellulose can be transformed into glucose on treatment with concentrated sulphuric acid. Since then many efforts have been made to put this epoch-making discovery to practical use. It is found, however, that as long as the normal sources of sugar and starch are undisturbed, the processing of wood for the production only of glucose may not be profitable. The process can be a success only in times of an emergency such as an extreme famine or a protected war. There are, however, many industries where wood waste as such or its partially-and fully-hydrolysed products occur as by-products, and their exploitation, where feasible, not only solves the problem of the disposal of the waste but also adds profits to the main industry. But even in such cases, the production of glucose or other sugars may not, except in special cases, be profitable. Almost the only scope for wood saccharification in normal times lie in the fact that certain products of great commercial importance like ethyl alcohol and yeast are obtainable from the sugar solutions by means of fermentation and that, therefore, saccharification can be organized for providing the raw material for the fermentation industries. Thus, despite early hopes, wood saccharification has not by itself yet become an established industry, and cellulose, the most abundant substance known to occur in nature, is far from being adequately epxloited for this purpose.

In most countries, timber is relatively an expensive material as compared to sugar. The saccharification process, where feasible, will justify the use only of wood waste and residues occurring in logging and manufacturing operations.

The wood saccharification industry has yet to be established in India. Available processes are suited mainly to special situations seldom met with in this country. The starting of the industry will have to await the development of suitable new processes as also industries to which saccharification is an accessory in the advanced countries.

Chemistry of saccharification

Saccharification, as already stated, is primarily the conversion of cellulose into glucose. In this process the accompanying hemi-celluloses and other polysaccharides also get affected. Of all the polysaccharides present in wood, the hemi-celluloses hydrolyse with the greatest ease. Water at a high temperature, dilute acids at 100°C and hydrolytic bacteria convert them into a stage of water-solubility; with a secondary hydrolysis they are completely hydrolysed. Under the same conditions, the cellulose remains practically unaltered. When, however, the acid concentration or the temperature is increased, cellulose begins to react. Under these altered conditions which hydrolyse cellulose to form soluble products in a matter of hours hemi-celluloses and the intermediate hydrolytic products change into simple sugars in seconds or minutes. Conditions which bring about the hydrolysis of cellulose rapidly, however also contribute to the decomposition of the resulting sugars, the pentoses undergoing the decomposition more rapidly than the hexoses. The problem is, therefore, to bring about the hydrolysis of cellulose as rapidly and completely as possible, preventing at the same time the decomposition of the monosaccharides. The hydrolysis can be affected both with concentrated acids and with dilute acids.

Saccharification processes

From what has been stated above it would be clear that the hydrolysis of wood is not simple and that there are technical and economic problems which limit its practice. Of particular significance is the fact that, while on the one hand the crystalline organization of cellulose results in a low accessibility of dilute acid commonly used as a catalyst, on the other, the conditions of high temperature and acid concentration necessary for a reasonably rapid hydrolysis result in the decomposition of the sugars formed. The few industrial processes that have been evolved in the face of these difficulties fall under one or the other of the following three categories :

(a) Dilute-acid batch processes.

(b) Dilute-acid percolation processes which increase yields by the expedient of continuously removing the product as it is formed.

(c) Concentrated-acid processes in which the crystaline organization of cellulose is destroyed and the carbohydrate solubilized and finally completely hydrolysed with dilute acid.

(a) *Dilute-acid batch processes*—The United States of America, Germany, and France were the pioneering countries in experiments on the hydrolysis of wood with dilute acids. The single-stage batch process, known as the 'American process', was the first industrial method used for making sugar from wood. It was simple, requiring relatively inexpensive equipment. The hydrolysing agent was 2 per cent sulphuric acid; the yield of sugar was low, being only 22 per cent by weight of drywood, or the equivalent of 90 litres (20 gallons) of alcohol per tonne of wood waste.

Several multi-stage batch methods have been suggested. In one process, wastewood in the form of shavings sawdust or chips is treated with 0.5 per cent sulphuric acid in the presence of steam at 190°C for about three minutes; the resulting sugars are removed by washing, the wood is treated second time with 0.7 per cent sulphuric acid at 215°C, and the resulting sugars are removed again. Yields of more than 50 per cent of sugars by dry weight of wood are claimed, but no commercial installations using the process are known.

(b) *Dilute-acid percolation processes.*—In saccharification by percolation processes, the wood is put into an acid resistant pressure vessel and hydrolised by dilute acid injected into the top of the vessel and the hydrolysate withdrawn through a filter in the bottom. In this way sugar production and extraction go on simultaneously and the sugar is separated and cooled as soon as possible to prevent decomposition. Two important processes, the Scholler process and the Madison wood-sugar process, may be mentioned under this type.

(i) *Scholler process*

The Scholler process is the most successful of all dilute-acid percolation processes and has stood the test of extensive industrial application in Germany and Switzerland. Typically, a Scholler plant contain a battery of 60-cubic-meter digesters, constructed of steel and lined with acid-resistant tile. The top of the digester has steam and vent lines and a line for the introduction of hot dilute acid. The bottom is

equipped with a porous tile filter. The digester is loaded with 9 to 10 tonnes of sawdust and chips. Hydrolysis is effected with dilute sulphuric acid (1.0 to 2.0 per cent for the first cycle and less than 1 per cent for the subsequent cycles). The wood is first steamed at about 134°, and the acid is injected at the top of the digester at 125°C. The acid is allowed to act for an hour. The sugar-containing solution is then withdrawn through the poroustile filter at the bottom of the digester. The residual chips and dust are reheated about 140°C, and fresh acid (less than 1 per cent concentration) is introduced at about 130°C and allowed to react for about haf-an-hour before the sugar solution is withdrawn as before. The treatment is repeated at successive higher temperatures until a temperature of 185°C is reached; Subsequent extractions are carried out at this temperature. In all, each charge is subjected to about 20 treatments of dilute acid, with the sawdust and chips steamed between successive treatments and takes about a day for completion. The total acid used works out to about 12 to 15 parts for every partof wood used and the sugar concentration is about 3 to 4 per cent. For production of alcohol or yeast,the total acid-sugar solution is heated again to complete the hydrolysis neutralized with lime or limestone, and then subjected to fermentation. The yield of sugar is 40 to 55 per cent of the weight of the wood giving a recovery of 20 per cent of alcohol on the weight of the wood as compared to about 26 per cent of alcohol by the Rheinau process (referred to later). Because of the short time interval between the formation of the sugars and their withdrawal, very little sugar degradation occurs as compared with the dilute-acid batch processes.

(ii) *Madison wood-sugar process*

This process was developed at the U.S. Forest Products Laboratory at Madison, Wisconsin, and is a modification of the Scholler process with a number of improvements. Here the inter-cyclic steaming of the Scholler process has been eliminated so as to effect time-saving of about three hours. Another change is that dilute acid of 0.5per cent is used and the temperature is raised gradually and continually from 150° to 185°C. Thirdly, the hydrolysate is withdrawn continuously to ensure the minimum retention time in the digester. TheSugar solution passes continuously from the hydrolyser to an expansion tank where steam and volatile products are partially flashed off, neutralized with lime under the existing pressure and filtered at the elevated temperature itself. The hydrolysate is subsequently worked either for alcohol or for yeast. The hydrolysis takes about three hours. The yield of sugarfrom Douglas fir (*Pseudotsuga taxifolia*) is found to be 50 per cent by weight, the average concentration of sugar in the solution being 5 per cent.

If it is intended to produce glucose, the dilute-acid hydrolysis should be carried in two different stages : (1) to hydrolyse and extract out the hemi-celluloses at lower temperature, and (2) to subsequently subject the hemi-cellulose-free residue to hydrolysis at a higher temperature. This second hydrolysate is neutralized, filtered and concentrated to about 60 per cent total solids. On cooling and seeding, glucose crystallizes out as a thick mass. It is separated by centrifugation, washed with sulphur-dioxide solution and recrystallized, using carbon black for decolorization. About 12 to 15 per cent of glucose on the weight of wood is usually obtained.

Classen patented a series of procedures for wood saccharification, using sulphurous acid as the hydrolysing agent. Introducing slight modifications into this method, a number of plants were constructed in Germany during World War I. A mixture of hydrochloric, sulphuric and sulphurous acids was used as the hydrolysing agent and the hydrolysis was done under pressure at elevated temperatures for short durations. After this treatment, the mass was extracted for sugars in diffusers.

(c) *Concentrated-acid processes.*—The use of large amounts of concentrated acid in these processes serves to break the bonds which hold cellulose in the crystalline state and make it highly resistant to dilute-acid hydrolysis; the fibres swell and dissolve to form viscous solutions. Soon the hydrolysis sets in and after a time the solution contains only oligo-saccharides and no mono-saccharides. Even if some glucose was formed during the above treatment, it would undergo some sort of condensation or reversion in the presence of concentrated acids to produce low polymers. These polymers are, however, water-soluble and behave like oligo-saccharides. On subsequent dilution with water and boiling, the cellulose breaks down almost quantitatively into glucose.

Cellulose fibres readily dissolve in 72 per cent sulphuric acid, 85 per cent phosphoric acid, or 45 per cent hydrochloric acid. For commercial exploitation, both sulphuric and phosphoric acids seem to be unsuitable because large amounts of the acids are required and there is no suitable method for their recovery. Hydrofluric acid also has been suggested for the hydrolysis because it is less corrosive to metals, but its recovery is not easy and, further, its fumes are poisonous. Hence fuming hydrochloric acid is employed in the industry, because the acid can be recovered almost completely by vacuum distillation. This was the basis for the Rheinau process of saccharification.

In the *Rheinau process*, which has had some degree of commercial success, the wood chips are air-dried and charged into a file-lined reacher and extracted counter currently by 41 to 45 per cent hydrochloric acid. The fresh acid comes in contact with the previously-treated wood chips, thus completing the hydrolysis of any unreacted cellulose and washing out the previously-formed sugars. The solution passes successively through chips in other reactors that have had less treatment and finally over fresh chips. Hydrolysis of the hemi-celluloses takes place last; it ends in building up the sugar concentration and decreases the length of exposure to the strong acid of the less-stable carbohydrate constituents. In order to maintain sufficient acid to prevent the formation of gelatinous products, the ratio of acid to wood is maintained at 7 to 1. The hydrolysis takes place at or below room temperature. By employing a series of reactors, it is possible to produce a solution containing 32 per cent by volume of reducing sugars. About 70 per cent of the weight of wood is dissolved, leaving a lignin residue containing about 7 times its weight of absorbed concentrated acid. The legnin, when washed free of acid and dried, can be used for fuel or charcoal production. The hydrolysate is then subjected to vacuum distillation at 35° to 45° C in order to remove the acid. The resulting thick syrup is dried in a spray dryer, when a solid containing 90 per cent of carbohydrate is obtained. This residue mostly contains oligo-sacchaides, because with concentrated hydrochloric acid either complete hydrolysis of the wood to simple sugars does not take place or the simple sugars, even if they are formed, once again undergo polymerization in the presence of the concentrated acid. However, the polymerized products are soluble in water and undergo further hydrolysis readily with dilute acid. So, the residue is dissolved in about three times its volume of water, made acidic so as to be 1 to 2 per cent acid, and heated at 120°C for 30 minutes. The resulting solution contains nearly 80 per cent of fermentable sugars. It can therefore be neutralized and concentrated to yield crystalline sugar or it may be directly subjected to fermentation.

More recent methods have aimed at using less of the acid. In one continuous process, patented in 1949, the hemi-celluloses are first removed by extraction with 27 to 33 per cent hydrochloric acid continuously in a cascade-type of equipment, and then the wet residue is treated with hydrogen chloride gas so as to bring the acid strength to 41 per cent. Sugar and acid are then removed in a concentrated solution, and the acid is recovered, as already described, by distillation in vacuum.

The process which has shown the greatest promise in recent years is the one known as the *Shoenemann process*, a modification of the Rheinau or Bergius process. Here chipped wood is pre-hydrolysed by batch boiling with 1 per cent hydrochloric acid at 129°C under pressure. This yields 22 per cent of mixed wood sugars, on the basis of dry wood, from the more easily hydrolysed hemi-celluloses. These sugars can be converted by evaporation into feed-molasses or, in the case of soft woods, fermented into alcohol. The pre-hydrolysed wood chips, now consisting mainly of cellulose and lignin, are dried and moved to the main hydrolysis tower where the cellulose is converted to sugar by counter-treatment with 41 per cent hydrochloric acid at about 21°C. Fresh acid is used on the nearly extracted chips, but an acid solution with progressively greater sugar concentration is employed on the less-hydrolysed chips in the digesters. The resulting sugar syrup is converted to dextrose by further mild hydrolysis, refinement and crystallization. The hydrochloric acid is separated from the sugar-acid concentrate by a three-stage vacuum evaporation and is brought to the required strength of 41 per cent by addition of hydrogen chloride gas. Lignin to the extent of 30 per cent by weight of dry wood is removed from the top of the tower. It can be used for the production of phenol-formaldehyde resins. (Panshin *et al* ; 1962).

All processes using concentrated hydrochloric acid give high yields of sugar, but have the serious disadvantage of corrosion of the equipment, thus necessitating the employment of costly acid-proof equipment. Further, though most of the acid is recovered and can be used again and again, the losses in the recovery are great.

Production of wood-molasses, alcohol and yeast

In most of the countries where wood saccharification is in vogue, it is not carried out for the production of glucose, because the isolation of this sugar is a matter of some difficulty, the pentoses interfering with its crystallization. Hence, if glucose production is aimed at, the pentose-yielding hemi-celluloses must first be eliminated by taking advantage of the fact that hemi-celluloses get hydrolysed more readily than cellulose. Therefore, a two-stage hydrolysis or, if it is continuous hydrolysis, a special technique has to be adopted. Hence the production of glucose from wood may not be quite economical in normal times except in countries like. Finland where sugar is in high demand and the other raw materials for glucose are not readily available. In many countries (U.S.A., Canada, Europe), the hydrolysate is used for the production of wood-molasses, alcohol and yeast.

Production of wood-molasses.—The hydrolysate is neutralized and then concentrated. The resulting product, known as wood-molasses, contains nearly 50 per cent reducing sugar. Although wood-molasses is too bitter and acidic for human consumption, it appears to be palatable to cattle and sheep, and may be used mixed with other feed. It has been suggested that the use of wood-molasses as a livestock feed supplement would provide the best opportunities for utilizing wood sugar in the U.S.A. (Panshin *et al* : 1962).

Production of alcohol.—Alcohol is produced from the hydrolysate by fermentation methods. In this process the high requirement of steam for recovering the alcohol is a great handicap. So, it appears to be more economical to first concentrate the wood-sugar solutions to about 15 per cent concentration before fermentation is started. In addition, there are several factors which adversely affect alcoholic fermentation. The chief among these is the formation during the hydrolysis of by-products like formic acid and furfural. However, the use of yeast in high concentrations and the stirring of the ferment overcome the inhibiting effects of the by-products; the use of large quantities of yeast also promotes rapid fermentation. Furthermore, acclimatization of the yeast improves the alcohol yield. Because wood-sugar solutions are sterile, yeast used in one fermentation remains free from contamination and can be used again and again in subsequent operations. From the fermented liquor the yeast is removed through continuous centrifuges as a thick cream, mixed with the sugar solution entering the first fermenter, and recycled. Under these conditions, the time of fermentation is about six hours. The yield of the alcohol varies with the species of wood used from 180 to 300 litres per tonne (40 to 65 gallons per ton). Apart from the factors stated above, the yields are also dependent on the amount of the nonfermentable sugars present in the hydrolysate. Softwoods usually yield hydrolysates containing 10 to 15 per cent of pentoses on the total reducing sugars, while hardwoods yield 30 to 40 per cent. In general, the pentoses are not fermentable by any strain of the usual yeasts (*Saccharomyces cerevisiae*). Certain other yeasts like *Torula utilis* and *Fusarium lini* can ferment pentoses also, but the fermentation is time-consuming and requires special conditions.

A convenient starting material for the production of alcohol is the sulphite waste liquor of the paper-pulp industry, and several countries are producing alcohol from this source.

Production of yeast.—Yeast proteins from wood-sugars as a source of food for humans and livestock acquired importance in Germany during the Second World War. Fodder yeast and baker's yeast are now produced in quantity in the U.S.A. and Canada from sulphite-pulping waste liquors. The yeast yields from wood hydrolysates and sulphite liquors workout to 40 to 50 per cent of the sugar utilize. Both hexoses and pentoses are capable of producing yeast, and in some countries the residual pentose left over after alcoholic fermentation of wood hydrolysates is utilized for the production of yeast. Several strains of yeast, like species of *Torus, Candida, Hansenula* and *Monilia*, multiply satisfactorily in sugar solution, but *Torus utilis* appears to be the best for fermenting wood-sugars. Food yeast propagated on wood contains about 50 per cent protein, 4 per cent fat, large amounts of vitamin B_2, and small quantities of vitamin B_1. Under suitable conditions 1 litre of 5 per cent wood sugar solution will produce 20 grams of yeast. (Panshin *et al* ; 1962).

The wood hydrolysate or the sulphite waste liquor is first neutralised with lime or limestone to approximately 3.5 pH, and filtered; the car filtrate, after the addition of the necessary nutrients like nitrogen, phosphate, magnesium and potash is employed for the growth of yeast. Trace elements like copper, cobalt, boron, etc., which are necessary for the yeast growth, appear to be present in the original solutions. Yeast is usually produced in a continuous operation; it continuously flows from the propagator to a separator which breaks the foam and separates the yeast as a thick cream. The latter is then heated at about 80°C in order to kill the organisms and the solution is finally dried in a drum dryer or spray dryer, when a solid is obtained.

Other by-products from wood hydrolysis

Several other products are obtained from wood hydrolysis either directly or indirectly. Lignin, methanol, formic and acetic acids, and furfural are some of the products produced during saccharification, and attempts have been made to recover them in order to make wood saccharification more attractive economically. Of these by-products lignin is the most important material, forming 16 to 30 per cent of the dry wood, and on account of its high carbon content it has a value both as industrial and domestic fuel. With the development of better and more profitable uses for this material—for instance, as glues and in thermosetting plastics—wood saccharification may take deep roots in many countries.

In addition to the above by-products , which are produced directly, many others are produced from the wood hydrolysate indirectly through fermentation. These are butanol, lactic acid, acetic acid, butyric acid, butylene glycol, "biosyn" (a kind of protein), etc. The crude wood-sugars may also be used as a starting material for the production of chemicals through chemical means like oxidation, reduction, dehydration, etc. A notable example is the production of furfural from pentoses. Others are lactic acid prepared through the action of alkali on the sugars and oxalic and tartaric acids obtained by oxidation.

REFERENCES

Hagglund, E. 1951 Chemistry of Wood ; Academic Press Inc. Publishers, New York.

Hall, J. A. *et al* 1956 Wood saccharfication—a summary statement; *Unasylva*, 10(1) : Documents Service F.A.O., Rome.

Panshin, A.J., Harrar, E.S., Bethel, J.C. & Baker, W.J. 1962 Forest Products, their Sources, Production and Utilization, 2nd Edition; MacGraw-Hill Book Company, New York.

Wise, L. E. & John, E.C. 1952 Wood Chemistry, 2nd Edition, Vols, I & II; Reinhold Publishing Corporation, New York,

CHAPTER XXI

CUTCH AND KATHA

Source of cutch and katha

Cutch and *katha* are obtained by boiling in water the heartwood of *Acacia catechu* (khair) a common tree found in the tropical deciduous and thorn forests of India, mainly in riverain tracts. The chief constituents of the heartwood are catechin (*katha*) and catechu-tannic acid (cutch). A third article of commerce is also obtained from this tree in the shape of a white powder, known as *kheersal*, which appears as a deposit in the wood. It is used for medicinal purposes, specially for cough and sore throat. In parts of South India, cutch is prepared from the heartwood of *Acaica chundra* (*A. sundra*) which replaces *A. catechu* there. In European commerce, the term 'cutch' also includes the extract of mangrove barks.

The average consumption of heartwood, in the factories and small-scale units of Uttar Pradesh, Madhya Pradesh and Bombay (now comprising Maharashtra and Gujarat), is given below :

TABLE XXI-1

Khair wood consumption for katha manufacture

(In tonnes)

States	Factories	Small-scale units	Total
Uttar Pradesh	11,500	9,700	21,200
Madhya Pradesh	4,650	12,000	16,650
Bombay (now comprising Maharashtra and Gujarat)	6,000	9,000	15,000
Total	22,150	30,700	52,850

Extraction of cutch

The preparation of cutch is carried out in different ways in different localities, though the main essentials are the same. The manufacturing season extends from November to February. The process is essentially one of extraction rather than distillation, in that the chips of wood are boiled down in water and are not treated with steam. The most generally used 'country' procedure for making cutch in the forest is roughly as follows :

The heartwood is cut into chips (Figs. XXI-1 & 2) which are boiled with water in earthen pots for about 12 hours. The time for which the chips are boiled depends upon their size: the smaller the chips the less would be the time for which they need to be boiled. Sometimes the liquid is poured into other pots in which liquid of a thicker consistency is boiling, and this process is continued until the liquid is of the correct consistency. Finally it is poured into an iron cauldron and further boiled and stirred until it attains the consistency of a syrup when it is poured out into wooden frames lined with leaves and allowed to cool. It then hardens in to a dark brown, solid, brick-like mass, in which form it is marketed.

The outturn of cutch obtained from a given quantity of heartwood depends upon the quality of the heartwood and the efficiency of the extraction. The smaller the chips the greater would be the outturn.

Extraction of katha

Katha is prepared from the heartwood, preferably that showing white specks of *kheersal* in the first stage, in the same way as cutch but the reboiled thick liquid is poured into moulds dug in fine sand which absorbs the tannic acid and leaves a residue of catechin to crystallize out into the *katha* of commerce. *Katha* is, therefore, similar to cutch but with most of the tannic acid extracted. It is used

extensively throughout India for eating with *pan*. It is not exported, but the Indian demand for this commodity is enormous. It is very astringent and is said to help digestion.

In some parts of Uttar Pradesh and West Bengal, the concentrated extract is aged, for about a week, in a boat-shaped container scooped out of semul (*Bombox ceiba* syn. *Salmalia malabarica*) logs before pouring it over porous beds. This treatment is believed to improve the taste of *katha*.

Modified method of extraction of cutch and katha

The rough 'country' methods of manufacturing both cutch and *katha*, as described above, are wasteful, because, when making cutch, it is not possible to recover the catechin or *katha*, while, in the manufacture of *katha*, the catechu-tannic acid (cutch) is allowed to go to waste in the sand in which the *katha* is collected. As a result of experiments carried out at the Forest Research Institute, Dehra Dun, it has been found possible to prepare cutch and *katha* at one and the same time by a slight modification of the country methods at present in vogue in most parts of the country (Fig. XXI-3). The procedure adopted is as follows :

The heartwood is chipped with axe in the ordinary manner. The chips are then placed in a vessel and boiled with water over an open fire, the time for which they are boiled depending on their size. This operation is best carried out in a tinned copper vessel. Tinning of copper vessels is essential to avoid contamination of *katha* with copper. The copper content of *katha* must not exceed 30 parts per million. Further work on the utilization of metallic vessels in the extraction of *katha* is in progress at the Institute. On no account should iron vessels be used, as the catechu-tannic acid (cutch) forms a greenish-brown compound with ferric salts and this impairs the colour of the cutch and *katha*.

The boiled liquid has to be further concentrated, and for this purpose it is poured into another vessel, straining it through a piece of muslin to remove all traces of chips, sand and other impurities. The liquid must be strained *while still hot* as otherwise there is the risk of the *katha* (catechin) crystallizing out on the cloth and so being lost. In the meantime, freshwater is added to the chips and they are again boiled. In some cases, as many as five boilings are made, but three should prove sufficient if the chips are small.

The liquid obtained by straining is now concentrated over a fire till the required density is obtained. Experiments have shown that at Dehra Dun in the cold weather it is best to concentrate the liquid till it attains a relative density of 1.07 to 1.08, but in other parts of the country where it is warmer it may prove better to concentrate the liquid still further. The density of the liquid is easily ascertained by means of a hydrometer. The optimum concentration can be ascertained by experiment, but in no case should the liquid be concentrated too highly as the catechu-tannic acid (cutch) retards the crystallization of the *katha* in thick solutions.

As soon as the liquid has attained the desired concentration it should be set aside for several days to cool slowly. While cutch is soluble in both hot and cold water, *katha* is soluble in hot water but very sparingly so in cold water. This fact is taken advantage of to separate the *katha* from the cutch in a hot concentrated solution of the two : cooling the solution adequately causes the *katha* to crystallize out. If the atmospheric temperature is high, it would be advisable to reduce the temperature of the solution further by immersing the vessel containing the liquid in cold water. As soon as the liquid has cooled sufficiently, it should be 'seeded' with some crystals of *katha*, as this accelerates the formation of *katha*. It will soon be found that there is a mass of crystals of *katha* at the bottom of the vessel.

It is now necessary to separate these crystals from the mother liquor, which consists of cutch and a small amount of *katha* which has not crystallized out. This is best done by straining the liquor through a fine muslin : the cutch in solution will pass through and leave the catechin on the muslin. It will probably be found that, when the liquor is first poured on to the muslin, some crystals of *katha* pass through the muslin, but this will cease when a bed of crystals has formed on the muslin, and only cutch in solution will then pass through, leaving the *katha* on the cloth. The cloth should be disturbed as little as possible while the filtration is in progress, so that the bed of crystals formed on it is not broken. Alternatively, a filter press may be used to separate these crystals.

KATHA MANUFACTURE

Fig. XXI—1. Chipping of khair heartwood

Fig. XXI—2. Boiling of khair chips in earthern pots.

KATHA MANUFACTURE

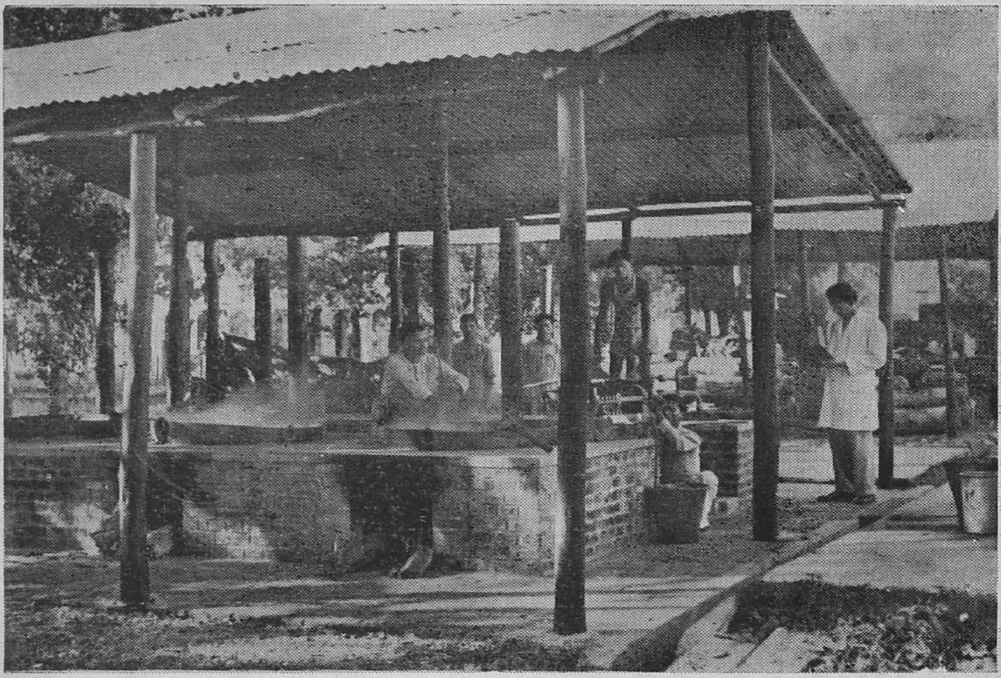


Fig. XXI—3. Katha units at the F.R.I., Dehra Dun.

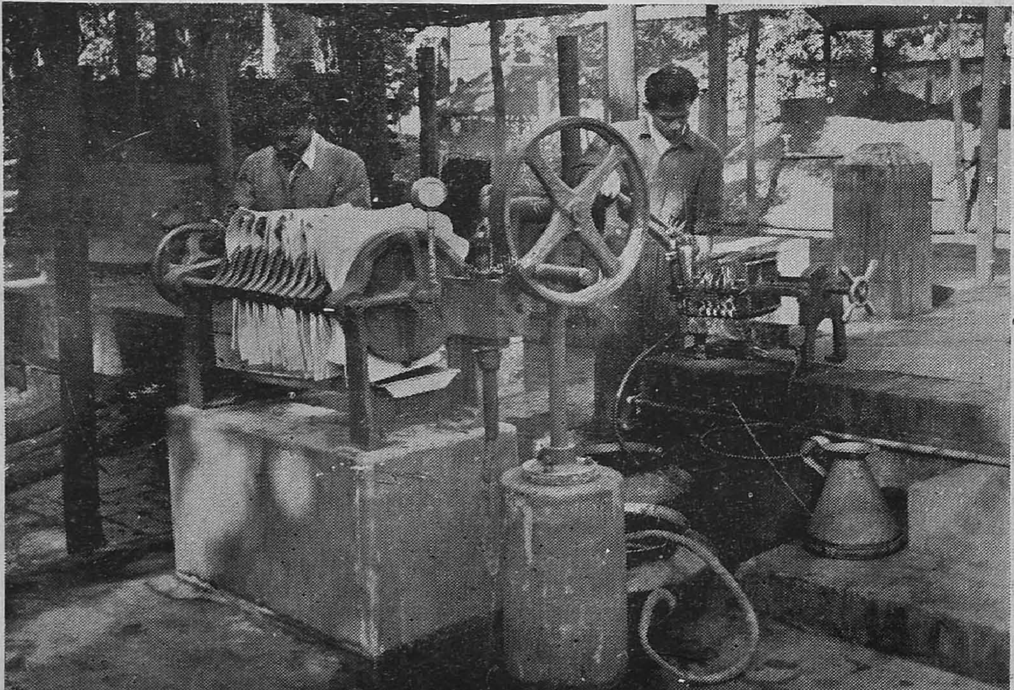


Fig. XXI—4. Filter press for katha filtration.

The *katha* adhering to the cloth after filtration may then be washed with some *pure cold water* to remove all traces of cutch. It should be scraped from the cloth and dried between sheets of cotton covered at top and bottom with sand. As soon as it has partially dried, it can be cut into cubes or other suitable sizes for the market and further dried and stored in racks with a free circulation of air till ready to be packed for despatch. The efficiency of extraction varies very considerably and the yield may be anywhere from 3 to 10 per cent by weight of the wood.

The mother liquor (containing mainly catechu-tannic acid or cutch) can be again concentrated after the extraction of *katha* till it attains a specific gravity of about 1.1, and then allowed to cools again so as deposit a further crop of *katha*, which can be removed as before. The final mother liquor thus obtained will be practically devoid of *katha* and can then be concentrated and made into cutch in the ordinary way (as explained earlier).

The amount of *katha* that can be obtained from a given quantity of wood depends on the *katha* content of the wood and the care taken in preparation. *All unnecessary heat should be avoided,* as this tends to oxidize the *katha* to form catechu-tannic acid (cutch).

Cutch is available in the form of small cubes or blocks, rusty-brown or dull-orange-black in colour. The product is hard and odourless with astringent taste and conchoical fracture.

Improved factory method of production of katha and cutch

Cutch and *katha* are being made on a large scale in up-to-date factories at Bareilly, Gwalior, Derol, Rajpipla, Vyara, etc. The principles of manufacture are the same except that all the operations are carried out by machine. Wood is chipped by disintegrators and extracted in copper vessels with hot water under slight pressure. The extract is concentrated in vacuum and cooled in a refrigerated tank for about a week, when *katha* crystallizes out. This is separated by filter presses (Fig. XXI-4), cut into slabs, and sliced into square tablets which are then dried. The yield of *katha* by this method is of the order of 4 to 4.5 per cent by weight of the wood. To obtained cutch, the mother liquor is further concentrated in Kestner evaporators to a consistency at which it solidifies on cooling, yielding cutch which forms 10 to 12 per cent by weight of the wood.

The quality of the cutch and *katha* thus produced by the scientific method shows a great improvement over that obtained by the old country methods, and it is probable that it will gradually oust the country method altogether.

Yield

The yield of *katha* and cutch varies considerably with the season in which the trees are felled and their girth, age and condition. The maximum yield of *katha* is obtained from trees felled in autumn and winter. Trees which have attained a girth of 60-120 cm and have white lines on them are generally preferred for the manufacture of *katha*. Trees that are gnarled and crooked are reported to give higher yields than straight ones. Freshly felled tree also give higher yields than dried ones. Dead trees are unsuitable for extraction; both yield and quality are affected by weathering. In Gujarat, khair trees from Baria Division are reported to give the best yield.

The following table gives the yield of *katha* and cutch per 100 kg of heartwood in different States.

TABLE XXI-2

Yield of katha and cutcp from khair wood

(In kg/100 kg of heartwood)

State	Factories		Small-scale units	
	Katha	Cutch	*Katha*	Cutch
Andhra Pradesh	—	—	2	3
Bombay (including Maharashtra and Gujarat)	4.5	12	3.4	10
Madhya Paadesh	1.5-1.7	10-12	3	—
Uttar Pradesh	4.5	10.5	—	—
West Bengal	—	10.5	6.3	—

Uses of cutch and katha

Cutch is an important commercial product and is used as a dyeing and preserving agent. Its chief industrial use in dyeing cotton and silk and in calico-printing. Different shades of colour are obtained in dyeing and printing with the use of mordants. Cutch dyes are usually preferred to coal-tar dyes, as the former exhibit greater fastness to weather condition and are less liable to mildew attack. Cutch is also used for dyeing and preserving fishing nets and ropes and for dyeing canvas for boat-sails and mail-bags to a reddish-brown colour. Materials treated with cutch are not affected by sea-water. Cutch can be used for the softening of loco feed-water and as a valuable raw material for plywood adhesives. Cutch is also used in medicine as an astringent, but is not satisfactory as a tanning agent, as the leather produced is harsh and is apt to contain yellow stains.

Katha is an indispensable ingredient in the preparation of chewing *pan*. The characteristic red coloration resulting from the chewing of *pan* is due to the combination of *katha* and lime. *Katha* is also used in medicine as an astringent and digestive. Externally it is employed as a cooling application to ulcers, boils and eruptions of the skin.

Production

The factory-made products are of the highest quality. The estimated production of *katha* and cutch in 1958 was as follows :

TABLE XVIII-3

Annual production of cutch and katha in 1958

(In tonnes)

Category	Organised production in factories	Unorganised production in small scale units	Total
Cutch	4,000-5,000	—	4,000-5,000
Katha	1,000-1,500	2,000-2,500	3,000-4,000

Trade

Production of cutch and cutch extract is more than adequate to meet internal requirement, and there is an appreciable export trade also. In 1963-64 there was a net export of 482 tonnes of cutch valued at Rs. 8,60,821 and of 152 tonnes of cutch extract valued at Rs. 4,30,723.

REFERENCES

Rao, P. R., Pathak, T. C. & Puntambekar, S. V. 1958 Manufacture of cutch and katha on cottage-scale basis; *Indian For.* 84 (11); Dehra Dun.

Sad Gopal 1956 Katha and cutch industry, latest developments by the Forest Research Institute; Reprinted from the *Himachal Times* (Forestry Supplement), Dec. 6, 1956.

Singh, Puran 1908 Anlysis of cutch and the preparation of pure catechin *Indian For. Leafl.* (1) ; F. R. I., Dehra Dun.

APPENDIX II

INSTRUCTIONS FOR COLLECTION OF MATERIAL FOR TESTING STANDARD CLEAR SPECIMENS FOR MECHANICAL PROPERTIES

1. *General*

When important timber species are required to be tested for keeping a record of authentic and comparable data on their physical and mechancial properties, material for each species is taken from a number of different localities, representative of different growth conditions and site qualities throughout the geographical range of the species. From each locality the selection, marking, etc. of the different consignments are governed by the instruction given in the following paragraphs. Moreover, all the details of the various trees should be given in the prescribed proforma for field notes given at the end of this Appendix.

2. *Selection*

Trees will be selected in the standing condition by one qualified to determine the species and understanding the various implications involved in conversion and testing. Whereve rnecessary and convenient, a representative of the testing authority will inspect the locality before felling.

Such trees will be selected for each category as appear to be healthy, dominant and of average growth. In species of high commercial importance, trees of merchantable size should be selected. While making the selection, the excessively fast or slow-grown trees, excessively clean-boled or branchy trees, or uncommonly straight or crooked boles, should be ignored so that the trees are *truly representative of average dominant trees in the locality.*

Ten such trees will be selected at random from different blocks and compartments in each case.

Immediately after selection, the representative of the testing authority may be informed of the location of the trees so that further special instructions, if any, may be considered.

3. *Marking and felling*

Before felling, the required details in the proforma for field notes should be carefully filled in.

Before felling, the breast-height should be marked with a ring of white or black paint at 1.37 metres 4½ from the ground level.

Before felling, the northern point and the serial number of the tree will be clearly marked on each tree (if necessary by removal of a small portion of bark) just below the ring. Any other required distinguishing mark to indicate the species and category to which the tree belongs should also be made. If numbers 6 and 9 are used, a line may be drawn underneath the figures to avoid confusion later.

The tree should be felled as near from the ground level as possible and in no case above 40 cm (16″ approx.) from the ground. Immediately after felling, the stump height should be measured and entered in the field notes.

A disc of 10 cm (4″ approx.) thickness should then be cut off from the top of the stump for despatching along with other material. The northern point and other distinguishing marks as given on the tree should also be written on the top side of the disc.

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When required for analysis, soil samples from each distinct horizon, or if the horizons are not distinct from 3 to 4 arbitrary depths, should also be collected from a pit up to 2 metres (6′ approx.) deep excavated near the tree immediately after felling, and should be packed in 20 cm × 25 cm (or 8″ × 10″) cloth bags, each sample weighing at leat 1 kg. All bags should be properly and adequately labelled to indicate the particular tree and disc as explained above.

Bark, leaves, flowers and fruits of the trees collected from the tree at the time of felling will help confirmation of the identity of the species. These should be sent except where for any reason it is not possible.

4. *Conversion and storing before despatch*

Immediately after felling, a 3 metre (10′ approx.) log from the butt end should be cut and stored on skids in a shady place. A prophylactic treatment may preferably be given to the log. Normally only one log is required from each tree, but where more than one log of 3 metre length are available and/or are necessary for testing, each should be given a separate log number and its relative position in the tree should be indicated.

The logs should not be debarked.

The marking of the northern point and other distinguishing marks as given on the tree should also be stamped or engraved on the smaller end (i. e., the top end), of each log.

The two ends of each log should be coated with coal-tar or varnished to prevent rapid drying and splitting, care being taken that no marking is obliterated by these paints.

The other details required in the proforma for field notes should then be completed.

5. *Despatching instructions*

The following will constitute one consignment :

(a) A minimum of 10 logs with at least one log from each tree.

(b) Ten corresponding discs from the stumps.

(c) Soil samples from under each tree when required.

(d) Fruit, flower, leaf, and bark samples of the trees.

If there are more than one consignments from a particular locality, a separate consignment number should be given to each and separate sets of proforma filled in for each consignment.

All the details in the proformas of the different consignments should be rechecked, signed and dated by the despatcher. These proformas should be sent along with despatch vouchers and R/R of the concerned consignment. The number of R/R or despatch voucher should be entered under item No. 13 of the proforma for field notes.

While loading and unloading the logs during transport at different stages, care should be taken that no bark is removed and no undue mechanical damage is caused to the log.

The least possible time should be taken between felling and despatch.

Each consignment should be despatched to the testing authority along with proper field notes.

PROFORMA FOR FIELD NOTES FOR COLLECTION OF MATERIAL FOR STANDARD TEST ON TIMBER

(To be filled at the time of collection and despatch of material)

Note : (i) All items are to be filled in but such items as do not apply may be crossed out. All information should be as complete as possible.

(ii) All measurements should be in metric system.

(iii) Items 1—23 pertain to all trees under the consignment; items 24—32 pertain to individual trees.

Name of collector ....Designation ....

1. (a Species...

   (b) Natural seedling, coppice or plantation...

   (c) Site quality ....

2. Name of State ....

3. Division and Range ....

4. Sketch map giving approximate scale of the area indicating the location of the selected trees by circled numbers 1, 2, 3, etc., corresponding to the numbers given on the trees. The number of the particular consignment and forest and geographical features should also be indicated. Block No. and Compartment No. may also be indicated. North direction should be indicated by an arrow.

5. Climate :

Mean annual temperature			Mean annual rainfall			Humidity
Max.	Min.	Mean	Total	Summer	Winter	

6. Approximate distance and direction of any nearby perennial/seasonal rivers or nullahs (give names)

   ....

7. Depth of water-table (Well) ....

8. Geological formation and rock ....

9. (a) Altitude ....

   (b) Aspect ....

10. Slope : Shape (convex or concave) ....

    Length ....

    Gradient (% or degree) ....

11. Vegetation : (Species in order of frequency)

    (i) Forest type and general description ....

    (ii) Overwood..

    (iii) Underwood .. ..

    (iv) Ground cover...

    (v) Regeneration of principal species ....

12. Soil mass Depth ....

    Root penetration (Depth and mode of distribution).....................................

    ....

    Fauna (Earthworms, white ants, rodents, etc.)...

    ....

13. Brief history of the site (Management practices, fire, grazing, felling, etc.) ....

    ....

14. (i) Land Form (Physiography) : Hill top/Hill slope/Plateau : or High terrace/Alluvial plain/ Valley bottom.

    (ii) Relief : Hilly excessive/Undulating normal/Flat upland sub-normal/ Flat lowland or flat concave.

15. (i) Drainage external (surface) : Waterlogged/Very slow/Slow/Medium/Rapid/Excessive.

    (ii) Internal (soil mass) ; None/Very slow/Slow Medium/Rapid/Excessive

16. Erosion : Slight/Moderate/Severe/Gullied

17. Deposition : None/Slight/Moderate/Excessive

18. Soil type : Red desert / Lateritic saline alkaline / Black marshy/Alluvial/ Brown forest/Hill.

19. Parent material : Formed in situ/Transported/Organic

20. Surface : Loose/Friable/Slight crusting/Compact

21. (i) Moisture top soil : Wet/Moist/Moderately dry/Dry/Very dry

(ii) Subsoil : Wet/Moist/Moderately dry/Dry/Very dry

22. Plant litter : Light/Moderate/Heavy

23. Organic matter : Little/Average/High/Excessive

The following information is required in respect of each tree. Normally only one log is required from each tree.

24. Distinguishing marks :

(a) On the small end ....

(b) At breats-height ....

(c) On the disc cut from stump ....

25. Age of the tree, if known ....

26. Total height of the tree ....

27. Girth over bark at breast-height, i.e., 1.37 metres....................

28. Date felling....................

29. Height of the stump....................

30. Date of converting into logs for storage ....

31. How are ends coated ....

32. Girth of the logs in cm at :

(a) Large end ....

(b) Small end ....

33. No. and date of R/R, or despatch voucher under which the material has been despatched. Also please give references of covering letter, if any....................

Signature of collector and date ....

Name and designation of despatcher....................

Signature and date (after completely verifying details before despatch) ....

....

APPENDIX III

DETERMINATION OF SUITABILITY CO-EFFICIENTS FOR WOODS

Several attempts have been made to evaluate suitability indices for various purposes, but the trend followed an more or less be generalized in the following manner. Certain necessary basic mechanical and physical properties are suitably adjusted and grouped together, separately for the different conditions in which wood may be used (e. g., green and dry for ordinary uses), and then a final composite index is obtained to indicate the suitability of the wood in question for any particular use in view. In the process of adjusting, the different mechanical properties that are relevant to a particular use are multiplied by what are called "Adjusting Factors" to bring all the values of different functions to the same order or magnitude as the principal strength factor which is of primary importance in the particular use in view. The adjusting factor is the average ratio of the principal strength factor to the auxiliary strength factor for a large number of species; where a large number is not available, the species which respresents the average properties is generally taken into consideration.

When all the concerned mechanical properties have been adjusted as above, each is multiplied by a suitable "Weightage Factor" to give relative importance which the particular property has for the particular use in view. These values are then added and the average is obtained for a given condition (say, green). Similar average values are also obtained for other conditions of the material. Then, by adding these values together, again with a proper weightage to each condition, the average value of these conditions is taken as "composite suitability figures". When this figure is expressed as a percentage of that of another species which is already in wide use and well known for any particular use (e.g., teak for most of the cases), the final value thus obtained is known as "comparative suitability index". To illustrate the above discussion algebraically the following example is given :

Let

A, B, C, etc.	be the different conditions of the material in which it may be used or in which the properties may be considered for any particular use;
S_A, S_B, S_C	the suitability figures in the respective conditions ;
q_1, q_2, q_3	the weightage factors for the different conditions, depending upon the importance of the condition;
S	the overall composite suitability figure for a particular species in question, taking all conditions into consideration;
S′	a similar overall composite suitability figure for a well known species in the use ;
$1 = \frac{S}{S'} \times 100$	the comparative suitability index, expressed as a percentage of the suitability figure of the well-known species;
P_o	the principal mechanical or physical property which comes into predominance in the use in question ;
W_o	the weightage to be given to the above property ;
P_1, P_2, P_3, P_n	the auxiliary properties which play a part in the use in question ;
F_1, F_2, F_3, F_n	the adjusting factors of the respective auxiliary properties; and
W_1, W_2, W_3, W_n	the weightage factors of the respective auxiliary properties.

Then for condition (A)—say, Green— the steps for obtaining the suitability figure can be written as follows :

	Adjusting Factor		*Weightage Factor*		
Principal property	$P_0 \times 1$	$\times$	W_0	=	$P_0 \; W_0$
Auxiliary property	$P_1 \times F_1$	$\times$	W_1	=	$P_1 \; F_1 \; W_1$
Auxiliary property	$P_2 \times F_2$	$\times$	W_2	=	$P_2 \; F_2 \; W_2$
Auxiliary property	$P_3 \times F_3$	$\times$	W_3	=	$P_3 \; F_3 \; W_3$
Auxiliary property	$P_i + F_i$	$\times$	W_i	=	$P_i \; F_i \; W_i$
Auxiliary property	$P_n + F_n$	$\times$	W_n	=	$P_n \; F_n \; W_n$

$$\text{Total} \left\{ P_0W_0 + \sum_{i=1}^{i=n} P_iF_iW_i \right.$$

Suitability figure for condition A ;

$$S_A = \left\{ \frac{P_0W_0 + \sum_{i=1}^{i=n} P_iF_iW_i}{W_0+W_1+W_2+ - - - +W_n} \right\}$$

Similarly the value for condition B (say, Dry) can be obtained as :

$$S_B = \left\{ \frac{P_0W_0 + \sum_{1}^{n} P_iF_iW_i}{W_0+W_1+W_2 + - - - +W_n} \right\}$$

Giving further necessary weightage to the exact condition, the overall composite suitability figure is given by :

$$S = \left\{ \frac{q_1S_A + q_2S_B + q_3S_C + - - -}{q_1 + q_2+q_3 + - - - - -} \right\}$$

which is the most generalised formula. In the ordinary cases where only Green and Dry conditions can be considered, a weightage of 2 is generally given to the green and of 1 to the dry conditions, as the basic data in green condition are more reliable for comparison between the species. The composite suitability figure in such a case is given by : $S = \frac{2S_A + S_B}{3}$

If S' is a similar figure for any well-known species already in use, for any particular purpose in view, then $I = \frac{S}{S'} \times 100$ where I is "comparative suitability index" as compared to the well-known species.

4.5 The adjusting factors, as given in most of the Forest Research Institute publications, are calculated from the test results obtained with teak, as this species was considered to be the wood of average qualities and was widely used. Also, in the earlier days strength data were not available for a large number of species. However, it may be seen that, as these adjusting factors have to remain constant for all the species (in any particular operation) that require to be compared for any particular use, it would be more appropriate to evolve the adjusting factors on the basis of a true "Average Wood". In U. S. A. (Markwardt : 1930) this seemed to have been the practice at the time of formulation of these adjusting factors, and where needed "Average Wood" was taken as of specific gravity 0.5 in both Green and Dry conditions. However, the more accurate adjusting factors derived from specific gravity—strength formulae of the concerned properties (Sekhar & Rawat : 1959) are indicated in the last columns of the Table-A for the Green and Dry conditions in the F.P.S. System and in the Metric System.

TABLE-A

Adjusting and weightage factors for different mechanical properties for different uses

Properties	Limaye, V.D. & Seaman, L. N. (1933)			Markwardt L. J. (1930)			Sekhar, A. C. & Rawat, B.S. (1959)	
	Adjusting Factor		Weightage Factor	Adjusting Factor		Weightage Factor	Adjusting Factor	
	Green	Dry		Green	Dry		Green	Dry
1	2	3	4	5	6	7	8	9
I. *Bending strength or Strength as a beam*								
1. M of R Static Bending	1.00	1.00	2	1.00	1.00	2	1.00	1.00
2. F.S. at E.L. Static Bending	1.61	1.50	1	1.72	1.54	1	1.69	1.73
3. F.S. at E.L. Impact Bending	0.68	0.74	1	0.74	0.82	1	0.69	0.81
II. *Stiffness as a beam*								
1. M of E Static Bending	1.00	1.00	2	1.00	1.00	2	1.00	1.00
2. M of E Impact Bending	0.77	0.76	1	1.00	1.00	1	0.70	0.72
3. M of E Comp. parallel to grain	Not used in India			1.00	1.00	1	Not used	
III. *Suitability as a post (Comp. strength endwise)*								
1. Max. Cr. Str. Comp. parallel to grain	1.00	1.00	1	2.20	1.85	2	1.00	1.00
2. F.S. at E. L. Comp. parallel to grain	1.44	1.47	1	2.82	2.52	1	1.40	1.46*
3. M of E Static Bending	3.51	4.53	1	Not used			3.49	4.24
IV. *Shock resisting ability*								
1. Work to Max. load Static Bending.	1.00	1.00	2	1.00	1.00	2	1.00	1.00
2. Total work Static Bending	0.34	0.43	1	0.41	0.52	1	0.39*	4.47*
3. Height of drop Impact Bending	0.266	0.428	1	0.31	0.34	2	0.268* (0.007)	0.347* (0.010)
V. *Retention of shape*								
1. Vol. shrinkage Green to oven-dry	1.00	—	2	1.00	—	2	—	—
2. Radial shrinkage Green to Oven-dry	2.96	—	1	1.00	—	1	—	—
3. Tangential shrinkage Green to Oven-dry	1.62	—	1	1.00	—	1	—	—
4. Ratio of $\frac{\text{Tangential}}{\text{Radial}}$	3.72	—	2	Not taken in use in U. S. A.			—	—

1	2	3	4	5	6	7	8	9
Retention of shape = $\frac{1}{\text{Srinkage}} \times 100$								
VI. *Hardness*								
1. F.S. at E.L. Comp. parallel to grain	1.00	1.00	2	1.00	1.00	2	1.00	1.00
2. Hardness test result Radial	1.01	1.30	1	0.89	1.24	1	0.94* (0.145)	1.07* (0.163)
3. Hardness test result Tangential	1.03	1.31	1	0.87	1.21	1	0.94 (0.145)	1.02* (0.159)
4. Hardness test result End	1.15	1.37	1	0.80	0.96	1	0.92 (0.143)	0.93 (0.145)*
VII. *Shear*								
1. Radial	1.00	1.00	1	Not done			1.00	1.00
2. Tangential	0.90	0.85	1				1.80	0.92

N.B. (i) Cols. (2) & (3) are based on values of teak; cols. (5) & (6) are based on specific gravity of average wood taken as 0.5; cols. (8) & (9) are based on strength—specific gravity formulae used in India and those indicated by an asterisk are based on the value of specific gravity of "Average Wood" in India taken as 0.592 for green condition and 0.630 for the air-dry condition.

(2) In the above table, except in the case of shock-resisting ability and hardness all the figures can be used both in the metric system and the F.P.S. system. The figures that should be used in metric system for the above properties are given in brackets in cols. (8) & (9). No such corresponding values are given in cols. (2) & (3) and in cols. (5) & (6).

If the units of the principal property and the auxiliary property are the same, then the adjusting factors will remain the same irrespective of whether it is F.P.S. System or Metric System.

If, however, they are different, as in the case of shock-resisting ability and hardness, the value of the factors will be different in the two different systems. The specific gravity-strength relationship is generally of the form $\sigma = K\rho^n$, where 'σ' = Strength property, 'ρ' = Specific Gravity and, 'K' and 'n' are constants. Hence it may be seen that in the Strength-specific Gravity equations, if the exponential value of 'ρ' in the principal and auxiliary strength factors are the same, specific gravity itself has no effect on adjusting factors. In the cases where these exponential values differ, the adjusting factors are calculated by taking the specific gravity of the "Average Wood" in Green and Dry conditions. Those falling in the latter group are indicated by an asterisk in the above table. It may also be observed from the table, that the differences between the calculated values and those in earlier use, are less in Green condition compared with the differences in the Dry condition. As timber is generally used in Dry condition, the accuracy of these factors in the Dry condition is thus felt to be more necessary.

APPENDIX IV

LIST OF TIMBER SPECIES, ARRANGED IN ALPHABETICAL ORDER GIVING THEIR DURABILITY AND 'TREATABILITY'

CLASS I

Average life 120 *months and above*

Sl. No.	Botanical Name	Source	Durability in months (Grave-yard test)			Treatability
			Average	Max.	Min.	
1	2	3	4	5	6	7
1.	*Acacia catechu**	Dehra Dun	380	383	372	—
2.	*Albizia lebbeck*	—	139	257	50	c
3.	*Albizia odoratissima*	—	189	294	81	e
4.	*Aphanamixis polystachya* (*Amoora rohituka*)	Assam	135	199	83	—
5.	*Artocarpus heterophyllus* (*A. integrifolius*)	Malabar	128	163	54	—
6.	*Artocarpus lakoocha*	Bihar & Orissa	239	311	203	—
7.	*Berrya ammonilla**	Burma	404	404	404	—
8.	*Careya arborea*	Uttar Pradesh	161	266	55	—
9.	*Cassia fistula*	Assam	121	186	76	—
10.	*Cedrus deodara*	Himachal Pradesh	179	317	115	c
11.	*Cinnamomum inunctum**	Burma	377	377	377	—
12.	*Cupressus torulosa*+	Garhwal	253	302	243	e
13.	*Dalbergia latifolia*	Madhya Pradesh	291	301	276	—
14.	*Dalbergia oliveri* *	Burma	418	418	418	—
15.	*Dablergia sissoo**	Uttar Pradesh	429	431	421	e
16.	*Diploknema butyracea* + (*Bassia butvracea*)	South Andamans	195	264	39	—
17.	*Dysoxylum malabaricum*	—	407	411	386	—
18.	*Eriolaena candollei*	Uttar Pradesh	126	238	87	—
19.	*Eucalvptus* sp. +	Nilgiris	161	205	26	e
20.	*Fagara budrunga** (*Zanthoxylum rhetsa*)	Tamil Nadu	143	200	70	—
21.	*Gluta tavoyana**	Burma	342	418	238	—
22.	*Gluta travancorica*	Tamil Nadu	127	287	24	—
23.	*Gmelina arborea*	Uttar Pradesh	214	242	200	—
24.	*Haplophragma adenophyllum* (*Heterophragma adenophyllum*)	Burma	201	323	88	c
25.	*Hardwickia binata**	Tamil Nadu	310	427	71	e

1	2	3	4	5	6	7
26.	*Hopea cordifolia**	Tamil Nadu	381	381	381	e
27.	*Hopea glabra**	Tamil Nadu	152	388	39	—
28.	*Hopea parviflora**	Tamil Nadu	390	418	251	e
29.	*Lagerstroemia hypoleuca*	Andamans	144	238	94	—
30.	*Lagerstroemia lanceolata*	Tamil Nadu	191	253	53	e
31.	*Lagerstroemia lanceolata*	—	162	234	41	e
32.	*Machilus macrantha*	Tamil Nadu	166	290	86	—
33.	*Madhuca indica** (*Bassia latifolia*)	Bihar & Orissa	239	425	32	e
34.	*Melanorrhoea usitata**	—	338	418	287	—
35.	*Mesua ferrea*	Assam	279	304	245	e
36.	*Mesua ferrea*	Tamil Nadu	146	227	45	e
37.	*Michelia montana*	Assam	121	167	57	—
38.	*Mimusops elengi*+	Tamil Nadu	125	234	15	—
39.	*Ougeinia oojeinensis* (*O. dalbergioides*)	Madhya Pradesh	122	122	122	—
40.	*Pentace burmannica*	Burma	171	262	108	d
41.	*Pentace griffithii*	Burma	229	289	170	—
42.	*Pentacme suavis**	Burma	415	415	415	—
43.	*Pterocarpus dalbergioides**	Andamans	419	431	383	c
44.	*Pterocarpus marsupium**	Maharashtra	339	420	234	e
45.	*Shorea robusta**	Burma	415	415	415	e
46.	*Shorea robusta**	West Bengal	269	287	180	e
47.	*Shorea robusta**	Ramnagar	253	282	186	e
48.	*Shorea robusta**	Gorakhpur	227	272	129	e
49.	*Shorea robusta**	Haldwani	288	288	288	e
50.	*Shorea robusta**	Uttar Pradesh	423	423	423	e
51.	*Soymida febrifuga**	Madhya Pradesh	356	418	298	—
52.	*Tectona grandis*	Madhya Pradesh	160	292	49	e
53.	*Vitex altissima**	Kanara	377	377	377	—
54.	*Xylia xylocarpa*	—	208	270	160	e
55.	*Xylocarpus molluccensis* (*Carapa molluccensis*)	Burma	296	360	254	—

*Some of the specimens are not yet rejected and are undergoing test in the yard. Their average life here is calculated on results obtained upto-date.

+Some of the specimens are found missing; the average life is, therefore, calculated upto their missing date.

Class II

Average life 60 to 119 months

Sl. No.	Botanical Name	Source	Durability in months (Grave-yard test)			Treatability
			Average	Max.	Min.	
1	2	3	4	5	6	7
1.	*Albizia procera*	Assam	75	127	32	c
2.	*Albizia procera*	Bihar & Orissa	97	103	71	c

1	2	3	4	5	6	7
3.	*Altingia excelsa*	Assam	76	118	13	e
4.	*Amoora wallichii*	West Bengal	81	96	65	—
5.	*Anogeissus acuminata*	Burma	74	132	38	c
6.	*Artocarpus chaplasha*	Assam	64	83	53	d
7.	*Bridelia retusa*	—	—	—	—	e
8.	*Calophvllum elatum* (*C. tomentosum*)	Tamil Nadu	63	81	44	—
9.	*Calophyllum elatum* (*C. tomentosum*)	Maharashtra	66	77	41	e
10.	*Castonopsis tribuloides*	Burma	87	87	87	—
11.	*Cedrela serrata*	Burma	78	101	51	—
12.	*Cleistanthus collinus*	Andamans	72	87	87	—
13.	*Delbergia rissoo*	—	73	104	55	e
14.	*Dipterocarpus indicus*	Coorg	81	103	53	b
15.	*Dipterocarpus zevlanicus*	Ceylon	64	80	40	b
16.	*Dysoxylum binectariferum*	Burma	83	87	74	—
17.	*Grewia tiliaefolia*	Tamil Nadu	71	118	59	d
18.	*Hopea odorata*	Burma	79	118	31	e
19.	*Kavea assamica*	Assam	67	91	18	e
20.	*Lagerstroemia microcarpa* (*L. lanceolata*)	—	80	112	42	e
21.	*Lagerstroemia microcarpa* (*L. lanceolata*)	—	111	127	62	e
22.	*Lagerstroemia speciosa* (*L. flos-reginae*)	—	88	183	59	e
23.	*Palaquium ellipticum* (*Dichopsis elliptica*)	Tamil Nadu	84	257	50	e
24.	*Parashorea stellata*	Burma	83	108	60	e
25.	*Phoebe hainesiana*	Assam	82	87	69	c
26.	*Podocarpus neriifolia*	Andamans	61	77	33	—
27.	*Poeciloneuron indicum*	Tamil Nadu	65	95	51	e
28.	*Protium serratum* (*Bursera serrata*)	Bihar & Orissa	97	185	22	e
29.	*Protium serratum* (*Bursera serrata*)	Burma	64	67	55	e
30.	*Quercus lineata*	Darjeeling	78	186	41	c
31.	*Radermachera xylocarpa* (*Sterospermum xylocarpum*)	Tamil Nadu	100	111	88	—
32.	*Shorea talura*	—	60	62	55	c
33.	*Syzvgium cumini* (*Eugenia jambolana*)	Bihar & Orissa	90	211	23	e
34.	*Syzgium kanarensis* (*Eugenia kanarensis*)	Burma	60	133	29	—
35.	*Terminalia arjuna*	South Chanda	119	122	108	b
36.	*Terminalia manii*	—	62	95	33	a
37.	*Terminalia paniculata*	—	60	62	55	e
38.	*Terminalia tomentosa*	Burma	105	153	55	b
39.	*Terminalia tomentosa*	Madhya Pradesh	81	118	67	b
40.	*Xylia dolabriformis*	Burma	97	190	38	e

CLASS III

Average life 59 months and below

Sl. No.	Botanical Name	Source	Durability in months (Grave-yard test)			Treat-ability
			Average	Max.	Min.	
1	2	3	4	5	6	7
1.	*Abies pindrow*	Uttar Pradesh	29	33	20	d
2.	*Abies pindrow*	Old N.W.F.P.	25	35	10	d
3.	*Abies spectabilis*	Himachal Pradesh	9	15	6	d
4.	*Acacia nilotica* ssp. *indica* (*A. arabica*)	Sind	39	51	34	b
5.	*Acacia nilotica* ssp. *indica* (*A. arabica*)	Sind	52	55	42	b
6.	*Acer campbelli*	Darjeeling	9	14	6	—
7.	*Acrocarpus fraxinifolius*	Pollachi (Malabar)	41	44	31	c
8.	*Adina cordifolia*	—	35	50	23	a
9.	*Adina cordifolia*	Bihar and Orissa	30	39	22	a
10.	*Adina cordifolia*	Uttar Pradesh	31	40	28	a
11.	*Aegle marmelos*	Gonda	27	20	22	—
12.	*Ailanthus grandis*	West Bengal	17	23	10	—
13.	*Albizia chinensis* (*A. stipulata*)	Bihar and Orissa	42	45	32	e
14.	*Albizia lucida*	Assam	30	46	23	e
15.	*Alcimandra cathcartii* (*Michelia cathcartii*)	West Bengal	26	31	24	—
16.	*Alstonia scholaris*	—	25	28	18	—
17.	*Anisoptera glabra*	Burma	32	53	22	—
18.	*Anogeissus latifolia*	Himachal Pradesh	29	31	42	e
19.	*Anogeissus pendula*	Jhansi	36	42	31	—
20.	*Anthocephalus cadamba*	Assam	16	23	9	a
21.	*Areca catechu*	—	—	—	—	e
22.	*Artocarpus heterophyllus* (*A. integrifolius*)	—	59	59	59	—
23.	*Artocarpus hirsuta*	Maharashtra	[46	46	46	—
24.	*Barmbusa arundinacea*	—	—	—	—	b
25.	*Bambusa nutans*	—	—	—	—	b
26.	*Bambusa polymorpha*	—	—	—	—	b
27.	*Bischofia javanica*	Assam	35	55	24	e
28.	*Bombax insigne* (*Salmalia insignis*)	Andamans	22	30	6	a
29.	*Bombax insigne* (*Salmalia insignis*)	Andamans	17	31	14	a
30.	*Bombax ceiba* (*Salmalia malabarica*)	Dehra Dun	12	12	12	a
31.	*Borassus flabellifer*	Bihar	55	124	6	b
32.	*Boswellia serrata*	Bihar and Orissa	21	44	13	e
33.	*Bruguiera* spp.	—	36	54	29	a

1	2	3	4	5	6	7
34.	*Bruguiera* spp.	—	24	29	18	a
35.	*Butea monosperma* (*B. frondosa*)	—	5	9	3	—
36.	*Calophyllum apetalum* (*C. wightianum*)	Maharashtra	59	81	38	e
37.	*Canarium euphyllum*	Andamans	9	14	7	—
38.	*Canarium strictum*	Tamil Nadu	20	36	11	—
39.	*Castanopsis hystrix*	Assam	38	38	38	b
40.	*Casuarina equisetifolia*	—	26	37	18	c
41.	*Cedrela toona*	Burma	31	38	21	c
42.	*Chloroxylon swietenia*	Madhya Pradesh	39	46	34	—
43.	*Chukrasia tabularis*	Assam	57	65	52	c
44.	*Cinnamomum cecicodaphne*	Dehra Dun	33	38	21	e
45.	*Cinnamomum iners*	Burma	43	46	33	—
46.	*Crateva nurvala* (*C. religiosa*)	Dehra Dun	9	9	9	—
47.	*Crypteronia paniculata*	Assam	33	46	23	b
48.	*Cryptocarya amygdalina*	Assam	12	23	3	—
49.	*Cryptomeria japonica*	Bengal	11	11	11	e
50.	*Cullenia excelsa*	Tamil Nadu	17	23	9	b
51.	*Cynometra polyandra*	Assam	36	55	24	b
52.	*Dalbergia paniculata*	Uttar Pradesh	45	62	37	—
53.	*Dendrocalamus hamiltonii*	—	—	—	—	b
54.	*Dendrocalamus strictus*	—	—	—	—	b
55.	*Dillenia indica*	Assam	25	29	20	a
56.	*Dillenia pentagyna*	West Bengal	18	20	12	d
57.	*Diospyros melanoxylon*	Madhya Pradesh	28	58	7	—
58.	*Diospyros pyrrhocarpa*	Andamans	19	37	11	—
59.	*Dipterocarpus alatus*	Burma	56	71	45	—
60.	*Dipterocarpus griffithii*	Andamans	41	51	21	c
61.	*Dipterocarpus griffithii*	Burma	23	27	20	c
62.	*Dipterocarpus kerrii*	—	33	37	25	—
63.	*Dipterocarpus macrocarpus*	Assam	37	46	29	a
64.	*Dipterocarpus obtusifolius*	Burma	44	45	38	—
65.	*Dipterocarpus tuberculatus*	Burma	46	67	38	b
66.	*Dipterocarpus turbinatus*	Burma	33	38	29	b
67.	*Duabanga sonneratioides*	West Bengal	33	50	20	c
68.	*Endospermum malaccense*	—	—	—	—	a
69.	*Engelhardtia spicata*	Assam	17	23	12	—
70.	*Eugenia gardneri*	Mangalore	49	50	42	d
71.	*Eugenia praecox*	Assam	32	40	26	e
72.	*Fraxinus excelsior*	Himachal Pradesh	13	21	8	—
73.	*Fraxinus floribunda*	Kashmir	12	29	6	—
74.	*Garuga pinnata*	Bihar and Orissa	13	13	13	e
75.	*Heritiera minor*	Pollachi (Malabar)	41	50	37	—
76.	*Heterophragma quadriculare* (*H. roxburghii.*)	Madhya Pradesh	34	70	17	—
77.	*Holoptelea integrifolia*	Uttar Pradesh	25	34	14	b

1	2	3	4	5	6	7
78.	*Homalium tomentosum*	Burma	55	64	46	b
79.	*Hymenodictyon excelsum*	Uttar Pradesh	22	34	15	c
80.	*Isonandra* spp. +	Assam	54	196	18	—
81.	*Juglans fallax*	Kashmir	14	19	6	—
82.	*Juglans regia*	Himachal Pradesh	22	31	7	—
83.	*Kayea floribunda*	Assam	25	25	25	—
84.	*Knema attenuata* (*Myristica attenuata*)	Tamil Nadu	6	6	6	—
85.	*Lagerstroemia parviflora*	South Chanda	51	58	38	e
86.	*Lagerstroemia tomentosa*	Burma	25	29	15	d
87.	*Lannea coromandelica* (*L. grandis*)	Uttar Pradesh	13	13	13	e
88.	*Lophopetalum wightianum*	Tamil Nadu	31	32	25	—
89.	*Machilus gamblei*	West Bengal	19	23	9	e
90.	*Machilus* spp.	West Bengal	36	41	29	—
91.	*Mallotus philippensis*	Dehra Dun	21	23	18	—
92.	*Mangifera indica*	Bihar and Orissa	25	33	23	a
93.	*Michelia champaca*	—	—	—	—	e
94.	*Michelia doltsopa* (*M. excelsa*)	—	15	28	9	e
95.	*Miliusa tomentosa* (*Saccopetalum tomentosum*)	Maharashtra	50	65	23	—
96.	*Miliusa velutina*	Dehra Dun	13	22	9	—
97.	*Mitragyna diversifolia*	Burma	27	38	8	b
98.	*Mitragyna parvifolia*	Bihar and Orissa	36	67	22	b
99.	*Morus alba*	Punjab	31	31	31	—
100.	*Morus serrata*	Himachal Pradesh	37	41	22	—
101.	*Parishia insignis*	Andamans	18	21	14	—
102.	*Parrotiopsis jacquemontiana* (*Parrotia jacuemontiana*)	Himachal Pradesh	11	14	7	—
103.	*Phoebe* spp.	—	21	29	8	c
104.	*Picea smithiana* (*P. morinda*)	Kashmir	14	23	9	d
105.	*Picea smithiana* (*P. morinda*)	Uttar Pradesh	24	40	20	d
106.	*Pinus wallichiana* (*P. excelsa*)	Himachal Pradesh	46	79	11	c
107.	*Pinus insignis*	Tamil Nadu	31	42	23	—
108.	*Pinus roxburghii* (*P. longifolia*)	Uttar Pradesh	34	44	14	b
109.	*Planchonia andamanica*	Assam	22	23	18	—
110.	*Podocarpus wallichianus*	Burma	26	46	6	—
111.	*Polyalthia fragrans*	Tamil Nadu	20	21	15	—
112.	*Pongamia pinnata* (*P. glabra*)	Maharashtra	18	23	17	—
113.	*Pterocymbium tinctorium* (*Sterculia campanulata*)	—	6	10	4	—
114.	*Pterospermum acerifolium*	—	18	28	16	c

1	2	3	4	5	6	7
115.	*Quercus lamellosa*	Darjeeling	27	29	17	c
116.	*Schima wallichii*	West Bengal	45	64	34	d
117.	*Schleichera oleosa* (*S. trijuga*)	Bihar and Orissa	55	95	39	a
118.	*Shorea assamica*	Assam	44	71	34	c
119.	*Sideroxylon longepetiolatum*	—	—	—	—	a
120.	*Sonneratia apetala*	West Bengal	20	21	14	—
121.	*Stereospermum personatum* (*S. chelonoides*).	Asssm	22	23	18	—
122.	*Stereospermum suaveolens*	Dehra Dun	17	25	13	—
123.	*Swintonia floribunda*	Burma	18	18	18	b
124.	*Terminalia arjuna* (sapwood)	Tamil Nadu	44	52	27	b
125.	*Terminalia arjuna* (mixed sapwood and heartwood)	Tamil Nadu	43	67	27	b
126.	*Terminalia arjuna*	Tamil Nadu	56	67	45	b
127.	*Terminalia arjuna*	Tamil Nadu	35	45	20	b
128.	*Terminalia bellirica* (*T. belerica*)	Bihar and Orissa	35	51	22	b
129.	*Terminalia bialata*	Andamans	43	55	25	e
130.	*Terminalia chebula*	Burma	43	67	24	c
131.	*Terminalia chebula*	Assam	12	13	9	c
132.	*Terminalia manii*	—	56	62	42	a
133.	*Terminalia myriocarpa*	Assam	54	62	37	a
134.	*Terminalia myriocarpa*	Assam	34	37	24	a
135.	*Terminalia oliveri*	Burma	59	127	32	e
136.	*Terminalia procera*	Andamans	37	39	28	b
137.	*Terminalia pyrifolia*	Burma	22	32	18	b
138.	*Tetrameles nudiflora*	Andamans	—	—	—	a
139.	*Ulmus wallichiana*	Himachal Pradesh	6	11	5	—
140.	*Vateria indica*	Tamil Nadu	27	28	23	e

+Some of the specimens are found missing; the average life is, therefore, calculated up to their missing date.

Treatability—In col. 7, the treatability of the heartwood of different species is indicated in five grades, each grade being defined as indicated below:—

(a) Heartwood easily treatable;
(b) Heartwood treatable, but complete penetration not always obtained;
(c) Heartwood only partially treatable;
(d) Heartwood refractory to treatment; and incision necessary for 13 mm to 20 mm penetration
(e) Heartwood very refractory to treatment penetration of preservative being practically nil even from ends.

APPENDIX V

RATES OF BURNING OF TIMBER SPECIES

Arranged in descending order of resistance tested at the Forest Research Institute, Dehra Dun.

(From I.F.B. No. 168 "Wood Preservation in India", 1956)

Group I

1. *Hardwickia binata*
2. *Diospyros* spp.

Group II

3. *Hopea parviflora*
4. *Terminalia tomentosa*
5. *Terminalia paniculata*
6. *Eucalyptus globulus*
7. *Shorea robusta* (sap)
8. *Berrya ammonilla*

Group III

9. *Bischofia javanica*
10. *Chloroxylon swietenia*

Group IV

11. *Borassus flabellifer*
12. *Xylocarpus molluccensis*
13. *Artocarpus hirsuta*
14. *Anogeissus latifolia*
15. *Tectona grandis*
16. *Quercus ilex*

Group V

17. *Schima wallichii*
18. *Acacia nilotica* ssp. *indica* (A. *arabica*)
19. *Pinus roxburghii*
20. *Stereospermum personatum*
21. *Vepris bilocularis*
22. *Diospyros* spp. (sapwood)
23. *Lagerstroemia* spp.
24. *Dipterocarpus* spp.
25. *Pterocarpus marsupium*
26. *Albizia lebbeck*
27. *Pterocarpus dalbergioides*
28. *Dalbergia sissoo*
29. *Terminalia bellirica*

Group VI

30. *Prunus cerasoides*
31. *Dalbergia latifolia*
32. *Albizia odoratissima*
33. *Calophyllum elatum*
34. *Cupressus torulosa*
35. *Adina cordifolia*
36. *Homalium tomentosum*
37. *Cedrela toona*

Group VII

38. *Juglans regia*
39. *Hymenodictyon excelsum*
40. *Tetrameles nudiflora*
41. *Terminalia bialata*

Group VIII

42. *Picea smithiana*
43. *Swietenia* spp.
44. *Terminalia myriocarpa*
45. *Mangifera indica*
46. *Morus* spp.
47. *Pinus wallichiana*

Group IX

48. *Moringa* spp.
49. *Anthocephalus cadamba*
50. *Bombax ceiba* (*Salmalia malabarica*)
51. *Endospermum malaccense*
52. *Erythrina variegata*
53. *Cryptomeria japonica*

APPENDIX VI

GROUPING OF TIMBERS FOR STRUCTURAL USE

(After Indian Standards Institution—IS : 833-1961)

Species for permanenet structures			Species for temporary structures
First choice		Second choice	
Naturally durable	Moderately durable or non-durable but easily treatable under open tank process	Moderately durable and non-treaiable but whose treatability can be improved for small sizes thickness upto 6 cm)	Non-durable and non-treatable
1	2	3	4
Group-Super, $E > 126{,}000$ kg/cm²; ft 180 kg/cm)²			
Acacia catechu	*Cynometra polyandra*	*Grewia tiliaefolia*	*Stereospermum personatum*
Albizia odoratissima	*Dipterocarpus macrocarpus*	*Poeciloneuron indicum*	
Bulanocarpus utilis	*Schleichera oleosa*		
Hopea glabra and			
H. parviflora			
Hopea nilis			
Mesua ferrea			
Mimusops elengi			
Pterocarpus santalinus			
Shorea robusta			
Vitex alissima			
Group-Standard. $E=98{,}000$ to $126{,}000$ kg/cm²; ft=120-180 kg/cm²			
Albizia lebbeck	*Acacia nilotica ssp. indica*	*Altingia excelsa*	*Anogeissus latifolia*
Diploknema butyracea	*Acrocarpus fraxinifolius*	*Amoora* spp.	*Atrocarpus hirsuta*
Dysoxylum malabaricum	*Casuarina equisatifolia*	*Anogeissus acuminata*	*Canarium strictum*
Eucalyptus euganioides	*Cullenia axcelsa*	*Carallia brachiata*	*Chloroxylon swietenia*
Gluta travancorica	*Dipterocarpus* spp.	*Grawia alastica*	*Cinnamomum* spp.
Kingiodendron pinnatum	*Terminalia chebula*	*Minusops elengi*	*Diospyros melanoxylon*
Lagerstroemio lanceolata	*Terminalia bellirica*	*Palaquium ellipticum* and	*Heritiera* spp.
Pterocarpus dalbergioides	*Terminalia manii*	*Palaguium polyanthum*	*Kayea floribunda*
Pterocarpus marsupivm	*Terminalia tomentosa*	*Syzygium* spp.	*Legerstroemia parviflora*
Shorea rubusta	*Quercus* spp.	*Terminalia paniculata*	*Machilus macrantha*
Soymida febrifuga			*Miliusa tomentosa*
Tectona grandis			*Planchonia andamanica*
Xylia dolabriformis			*Terminalia bialata*
Xylocarpus molluccensis			
Group—Ordinary $E=56{,}000$ to $98{,}000$ kg/cm²; ft=85-120 kg/cm²			
Artocarpus heterophyllus	*Adina cordifolia*	*Artocarpus chaplasha*	*Abies pindrow*
Artocarpus lakoocha	*Albizia procera*	*Bridelia ratusa*	*Aegle marmelos*
Azadirachta indica	*Anthocephalus cadamba*	*Calophyllum* spp.	*Ailanthus grandis*

1	2	3	4
Madhuca indica	*Castanopsis hystrix*	*Dalbergia sisso*	*Anisoptera glabra*
Careya arborea	*Cedrela* spp.	*Elaeocarpus tuberculatus*	*Bischofia javanica*
Cedrus deodara	*Chukrasia tabularis*	*Lagerstroemia speciosa*	*Boswellia serrata*
Cupressus torulosa	*Dillenia* spp.	*Lagerstroemia hypoleuca*	*Diospyros melanoxylon*
Dalbergia latifolia	*Holoptelea integrifolia*	*Podocarpus* spp.	*Duabanga sonneratioides*
Dalbergia sissoo	*Mangifera indica*		*Garuga pinnata*
Gmelina arborea	*Mitragyna parvifolia*		*Heterophragma quadriculare*
Hardwickia binata	*Pinus wallichiana*		*Juglans* spp.
Ougeinia oojeinesis	*Pinus roxburghii*		*Knema attenuata*
Tectona grandis	*Phoebe* spp.		*Lophopetalum wighatianum*
	Pterospermum acerifolium		*Machilus macrantha*
	Stereospermum personatum		*Michelia* spp.
	Swintonia floribunda		*Miliusa velutina*
	Terminalia arjuna		*Morus* spp.
	Terminalia myriocarpa		*Picea smithiana*
			Polyalthia fragrans
			Pongamia pinnata
			Schima wallichii
			Shorea assamica
			Sonneratia apetala
			Terminalia procera
			Vateria indica

Note : E stands for modulus of elasticity.

APPENDIX VII (a)

GRADING RULES OF THE NILGIRIS FOREST DIVISON

The classification and grading of timber is done as follows :—

Teak **:** (i) T.R.A. (Teak round, 'A' Class) Straight and Sound logs 2.44 m (8') up in length.

T.R.A. I—152 em (60") and up in mid girth.

T.R.A. II—122 cm (48") to 150 cm (59") in mid girth.

T.R.A. III—89 cm (35") to 119 cm (47") in mid girth.

(ii) T.R.B. (Teak round, 'B' Class) Logs 2.44 m (8') and up in length with minor defects.

T.R.B. I—152 cm (60") and up in mid girth.

T.R.B. II—122 cm (48") to 150 cm (59") in mid girth.

T.R.B. III—91 cm (36") to 119 cm (47") in mid girth.

(iii) T.R.C. (Teak round, 'C' Class) Logs 2.44 m (8') and up in length not qualifying for the A and B classes. Usually logs with bad shape and major defects fall under this class.

T.R.C. I—152 cm (60") and up in mid girth.

T.R.C. II—91 cm (36") to 150 cm (59") in mid girth.

(iv) T.R.S.L. (Teak round short logs) Logs between 1.22 m (4') and 2.36 m (7'9") in length and 91 cm (36') and above in girth.

(v) T.P. (Teak poles) T.P. I and T.P. II classes are measured as in the case of logs. But in the case of T.P. III, T.P. IV, T.P.C. and T.P.U.S. classes a standard volume of 0.056 cu m (2 cu ft), 0.042 cu m (1.5. cu ft), 0.028 cu (1 cu ft) and 0.021 cu m (0.75 cu ft) respectively is adopted for accounting purposes.

T.P. I—Teak poles 4.57 in (15") and up in legnth and 61 cm (24") to 89 cm (35") in mid girth.

T.P. II—Teak poles 3.04 in (10') to 4.57 in (15') in length and 61 cm (24") to 89 cm (35") in mid girth.

T.P. III—Teak poles 4.57 m (15') and up in length and 30 cm (12") to 89 cm (35") in mid girth.

T.P. IV—Teak poles 3.04 m (10') to 4.57 m (15') in length and 30 cm (12") to 89 cm (35") in mid girth.

T.P.C.—Teak poles 30 cm (12") to 89 cm (35") in mide girth and not qualifying to any of the four classes mentioned above.

T.P. U.S.—Teak poles undersized 3.04 m (10") and up in length, 23 cm (9") in mide girth.

Note.—Teak logs are not rough squared at present. If they are squared, the corresponding classes will be T.A.I, T.A. II, T.A. III, T.B. II, T.B. III, T.C. I and T.C. II according to the girth and length specifications given for the round logs detailed above.

Rosewood.—Rosewood logs are rough squared before transport. The different classifications followed are as follows :

R.W.A. I—Straight and sound logs 2.44 m (8') and up in length and 152 cm (60") to above in mid girth.

R.W.A. II—Straight and sound logs 2.44 m (8′) and up in length and 122 cm (48″) to 150 cm (59″) in mid girth.

R.W.B. I—Logs 2.44 m (8′) and up in length with minor defects and 152 cm (60″) and above in mid girth.

R.W.B. II—Logs 2.44 m (8′) and up in length with minor defects and 122 cm (48″) to 150 cm (59″) in mid girth.

R.W.C.—Logs not qualifying to the above classes due to major defects: 2.44 m (8′) and up in length and 122 cm. (48″) and up in mid girth.

R.W.P.A.—Sound poles 2.44 m (8′) and up in length and 64 cm (25″) to 119 cm (47″) in mid girth and not qualifying for R.W.P.A. classes.

Other hardwoods.—Timber other than teak and rosewood.

A Class — Straight and sound logs 2.44 m (8′) and up in length, 122 cm (48″) and up in mid girth.

B Class — Logs 2. 44 m (8′) and up in lehgt and 122 cm (48″) and up in mid girth but not qualifying for the A Class.

Poles : Straight and sound poles 2. 44 m (8′) and up in length and 91 cm (36″) to 119 cm (47″) in mid girth.

APPENDIX VII (b)

GRADING RULES OF THE COIMBATORE SOUTH FOREST DIVISION

Classification of timber.—Th e following classification is adopted for teak timber in the Coimbatore South Division.

Quality classification

'A'	Logs without knots, cracks, splits, etc.
'B'	Logs with slight defects such as bends, knots, etc.
'C'	Poor quality logs.

Length and girth classification.—(For teak and rosewood only)

'ALI'	'A' class logs over 4.57 m (15') in length and 152 cm (60") and over in girth.
'ALII'	'A' class logs over 4. 57 m (15') in length and 122 cm (48") to 150 cm (59") in girth.
'ALIII'	'A' class logs over 4. 57 m (15') in length and 91 cm (36") to 119 cm (47") in girth.
'ASI'	'A' class logs 2.44 m (8') to 4.57 m (15') in length and 152 cm (60") and over in girth.
'ASII'	'A' class logs 2. 44 m (8') to 4.57 m (15') in length and 122 cm (48") to 150 cm (59") in girth.
'ASIII'	'A' class logs 2. 44 m (8') to 4.57 m (15') in length and 91 cm (36") to 119 cm (47") in girth.
'BI'	'B' class logs over 152 cm (60") in girth.
'BII'	'B' class logs over 122 cm (48") to 150 cm (50") in girth.
'BIII'	'B' clas logs over 91 cm (36") to 119 cm (47") in girth.
'CI'	'C' class logs of 152 cm (60") and over in girth.
'CII'	'C' class logs of 122 cm (48") to 150 cm (59") in girth.
'CIII'	'C' class logs of 91 cm (36") to 119 cm (47") in girth.

Note.—Length is not taken into consideration in the case of B and C class logs but all logs below 2.44 m (8') in ength irrespective of the quality are included in the C class.

All teak logs below 91 cm (36") in girth are classed as CIV irrespective of quality or length.

Classification of species other than teak and rosewood;

'AI'	A class logs of over 152 cm (60") in girth.
'AII'	A class logs of over 122 cm (48") to 150 cm (59") in girth.
	Logs below 122 cm (48") in girth are included in the B class.

Note.—Length is not taken into consideration in the classification of miscellaneous species.

APPENDIX VII (c)

SPECIFICATION OF TIMBERS IN THE DEPOTS OF WESTERN KANARA DIVISION, MYSORE STATE

1. *Logs*

(a) Teak(*Tectona grandis*).—2.4 m(8′) and up in length and 107 cm (42″) and up in mid girth in the round; only a strip of bark at mid girth being removed for measurement. Badly fluted logs or logs with curvature need only be squared if they give a squared log of 91 cm (36″) midgirth. Not more than 8 cm (3″) wane will be allowed.

(b) Rosewood (*Dalbergia latifalia*).—2. 4 m (8′) and up in length and 107 cm (42″) and up in mid girth in the round trimmed down to heartwood.

(c) Matchwood logs.—The logs of *Bombax ceiba*, *Machilus macrantha*, *Canarium strictum* and *mangifera indica* 2. 1 m (7′) and up in length and not less than 84 cm (33″) in the middle, 76 cm (30″) at the butt-end, in girth over bark. Logs should be green, sound, cylindrical, freshly cut and with bark on. Material should be converted and delivered at the prescribed depot within fifteen days after the trees are felled.

2. *Mill pieces*

(a) *Teak.*—1. 4 m (4½′) and up in length and 84 cm (33″) and up in girth at thin end over bark. All the pieces should be over 2. 1. m (7′) in length as far as possible.

(b) *Teak scantling.*—1.4 m (4½′) and up in length and 61 cm (24″) to under 84 cm (33″) in girth at thin end over bark.

(c) *Rafters*—

Class	Length	Girth at butt-end	Girth at top end
I	3.7 m (12′) and up	61 cm (24″) to under 91 cm (36″)	31 cm (12″)
II	Do.	41 cm (16″) to under 61 cm (24″)	23 cm (9″)
III	Do.	31 cm (12″) to under 46 cm (18″)	—

Note.—Class I and II poles of teak, laurel (*Terminalia tomentosa*), kindal (*Terminalia paniculata*), irul (*Xylia xylo arpa*) and rosewood (*Dalbergia latifolia*) only are usually extracted and not of any other species, while class III poles of eak only are extracted and not of any other species.

(d) *Transmission poles*

	Length of the Pole		Girth	
	Minimum	Maximum	Top	Bottom
1.	7.3 m (24′)	7.9 m (26′)	36-38 cm (14″—15″)	53—58 cm (21″—23″)
2.	8.2 m (27′)	9.1 m (30′)	41—43 cm (16″—17″)	58—64 cm (23″—25″)
3.	9.4 m (31′)	10.7 m (35′)	41—43 cm (16″—17″)	64—69 cm (25″—27″)
4.	11.0 m (36′)	12.2 m (40′)	56 cm (22″)	91 cm (36″)

Note.—Transmission poles of only teak are usually extracted.

APPENDIX VII (d)

SPECIFICATION FOR CLASSIFICATION OF TEAK LOGS AND POLES IN KERALA STATE

Sl. No.	Designation of the class		Description	Mid girth in		Length in	
				Centimetres	Inches	Metres	Feet
1	2		3	4	5	6	7
1. *Logs*							
	Class A	I	Straight and perfectly sound. Not more than one big knot per every 1.83 metres (6 ft) length	153 and up	60 and up	2.44 and up	8 and up
		II	—do—	122 to below 153	48 to below 60	—do—	—do—
		III	—do—	below 122	below 48	—do—	—do—
	Class B	I	Fairly straight and sound with flutes, knots and slight splits	153 and up	60 and up	2.44 and up	8 and up
		II	—do—	122 to below 153	to below 60	—do—	—do—
		III	—do—	below 122	below 48	—do—	—do—
	Class C	I	Defective, which do not fall under A and B classes	153 and up	60 and up	2.44 and up	8 and up
		II	—do—	122 to below 153	48 to below 60	—do—	—do—
		III	—do—	below 122	below 48	—do—	—do—
	Small logs		Fairly straight and sound	77 and up	30 and up	below 2.44	below 8
2. *Poles*							
	Class	I	A Fairly straight and sound	66 to 77*	26 to 30*	above 12.20	above 40
			B —do—	—do—	—do—	above 9.15 to 12.20	above 30 to 40
			C —do—	—do—	—do—	9.15 and below	30 and below
			D Defective and crooked	—do—	—do—	Any ength	Any length

1	2	3	4	5	6	7
Class	II	A Fairly straight and sound	54 to 64	21 to 25	above 12.20	above 40
		B —do—	—do—	—do—	above 9.15 to 12.20	above 30 to 40
		C —do—	—do—	—do—	9.15 and below	30 and below
		D Defective and crooked	—do—	—do—	Any length	Any length
Class	III	A Fairly straight and sound	41 to 51	16 to 20	—do—	—do—
		B Defective and crooked	—do—	—do—	—do—	—do—
Class	IV	Fairly straight and sound	28 to under 39	11 to under 15	—do—	—do—
Class	V	Fairly straight and sound	26 and below	10 and below	—do—	—do—

*Girth under bark at 3.05 metres (10 ft) from butt-end.

APPENDIX VIII

MARKING RULES

(As being followed in Shiwalik Circle, Uttar Pradesh)

Marking instructions

1. Every tree marked must have to blazes, an upper and a lower, on opposite sides, and these blazes must be of a size sufficient to make them easily recognisable as marking blazes.
2. Whenever a tree is selected for lopping, in order to avoid damage in felling, and 'L' mark should be placed in coal-tar on the upper blaze.
3. Generally two hammer marks will be put on each blaze, one of these will be dabbed with coal-tar to safeguard against its disappearance by white-ant damage.
4. All trees of commercially important species above 30 cm in diameter, which are marked for felling, are serially numbered species-wise for each lot; and classified into Sound (S), Fit (F) and Unfit (U) categories. The serial numbers, as well as the classification marks, will be stamped with iron dies on both the blazes.
5. Sal and Sain trees of 20-30 cm diameter class will be classified into Fit and Unfit categories only.
6. In actual marking in the forest, trees must be called out by the hammer-man and by no one else.

Classification of trees into Sound, Fit and Unfit

Trees marked for sale are generally classified into *Sound, Fit* and *Unfit*. The definitions of these categories have been standardised by the Territorial Conservator of Forests. The classification adopted for Sal and Sain trees in Dehra Dun. West and East Forest Divisions is given in the following table (Source : Working Plan for the West and East Dehra Dun Divisions, 1969-70 to 1978-79, by D.N. Misra, I.F.S.) :

Diameter class (cm)	Classification	I Quality: Length of commercial bole in m	I Quality: Volume cu m	II Quality: Length of commercial bole in m	II Quality: Volume cu m	III Quality: Length of Commercial bole in m	III Quality: Volume cu m	IV Quality: Length of Commercial bole in m	IV Quality: Volume cu m
20—30	Classified into fit and unfit only.								
	Fit is reasonably straight and capable of giving sawn timber. Unfit is a Cooked tree not capable of yielding any sawn timber.								
30—40	Sound	9·8 & over	0·3 & over	7·3 & over	0·2 ver	5·5 & over	0·2 & over	4·9 & over	0·1 & over
	Fit	4·9 to 9·8	0·2 to 0·3	3·7 7·3	0·1 to 0·2	2·7 to 5·5	0·1 to 0·2	2·4 to 4·9	0·08 to 0·1
	Unfit	Less than 4·9	Less than 0·2	Less ?	Less than 0.1	Less than 2·7	Less than 0·1	Less than 2·4	Less than 0·08
40—50	Sound	More than 11	0 ·6 & over	8·5 & over	0·5 & over	6·7 & over	0·3 & over	6·1 & over	0·3 & over
	Fit	4·9 to 11·0	0·4 to 0·6	4·3 to 8·5	0·3 to 0·5	3·4 to 7·3	0·2 to 0·4	3·0 to 6·1	0·2 to 0·3
	Unfit	Less than 5·5	Less than 0·4	Less than 4·3	Less than 0·3	Less than 3·4	Less than 0·2	Less than 3·0	Less than 0·2
50—60	Soun	More than 11·6	10·8 & over	9·8 & over	0·8 & over	7·3 & over	0·7 & over	6·7 & over	0·5 & over
	Fit	5·8 to 11·6	0·7 to 0·74	4·9 to 9·8	0·5 to 0·8	3·6 to 7·3	0·4 to 0·7	3·4 to 3·7	0·3 to 0·5
	Unfit	Less than 5·8	Less than 0·7	Less than 4·9	Less than 0·5	Less than 3·6	Less than 0·4	Less than 3·4	Less than 0·3
60—70	Sound	12·2 & over	1·5 & over	10·4 & over	1,3 & over	7·9 & over	1·0 & over	7·3 & over	0·8 & over
	Fit	6,1 to 12·2	1·0 to 1·5	5·2 to 10·4	0·8 to 1·3	3·9 to 7·9	0·4 to 0·6	3·6 to 7,2	0,4 to 0,8
	Unfit	Less than 6·1	Less than 1·0	Less than 5·2	Less than 0·8	Less than 3·9	Less than 0·6	Less than 3·6	Less than 0·4
70—80	Sound	12·8 over	2,1 & over	11·0 & over	1·8 & over	7·9 & over	1·4 & over	7.3 & over	1·4 & over
	Fit	6·4 to 12·8	1·3 to 2·1	5·9 to 11·0	1· to 1·8	4·3 to 8·5	0·8 to 1·4	3·6 to 7·3	0·7 to 1·1
	Unfit	Less than 6·4	Less than 1·3	Less than 5·9	Less than 1·1	Less than 4·3	Less than 0·8	Less than 3·6	Less than 0·7

Note.— The quality classes have been based on Yield Table by Smythies & Howard with classification as below :

Quality I—Trees of more than 33·5 m in height.
Quality II—27·4 m to 33·5 m in height.
Quality III—21·3 m to 27·4 m in height.
Quality IV—Less than 21·3 m in height.

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